High Intensity Negative Ion Sources

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Snowmass'01

Working Group on High-Intensity Proton Sources

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Brightness of an ion beam:

$$B = 2I^{-}/\pi^2 E_x E_y$$

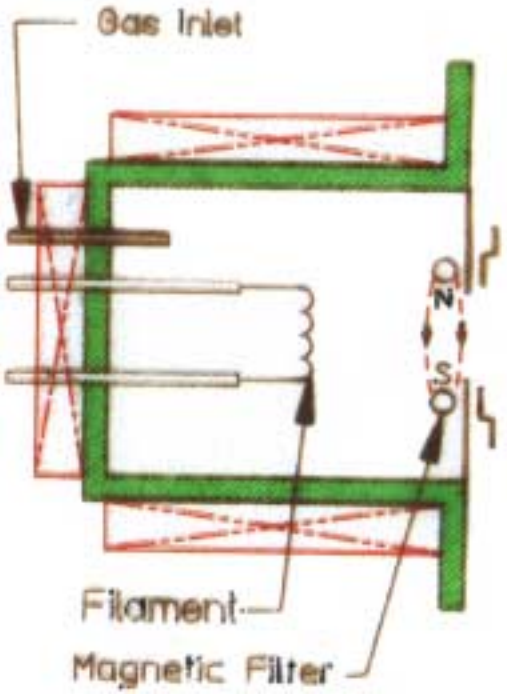
$$= 2J^{-}Mc^2/\ \pi^2 T_i$$

Three Types of H^- Ion Sources

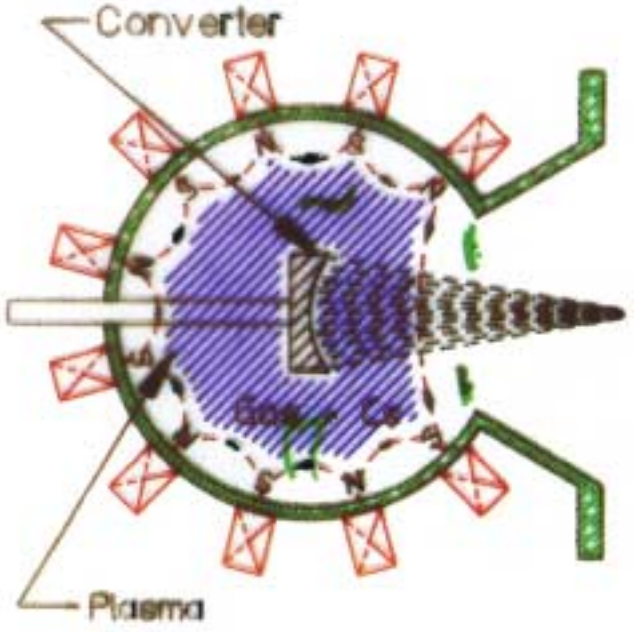
- Surface conversion sources
- Volume production sources
- Hybrid production sources
  (or surface plasma sources)

Two Ion Source Technologies for Neutron Science

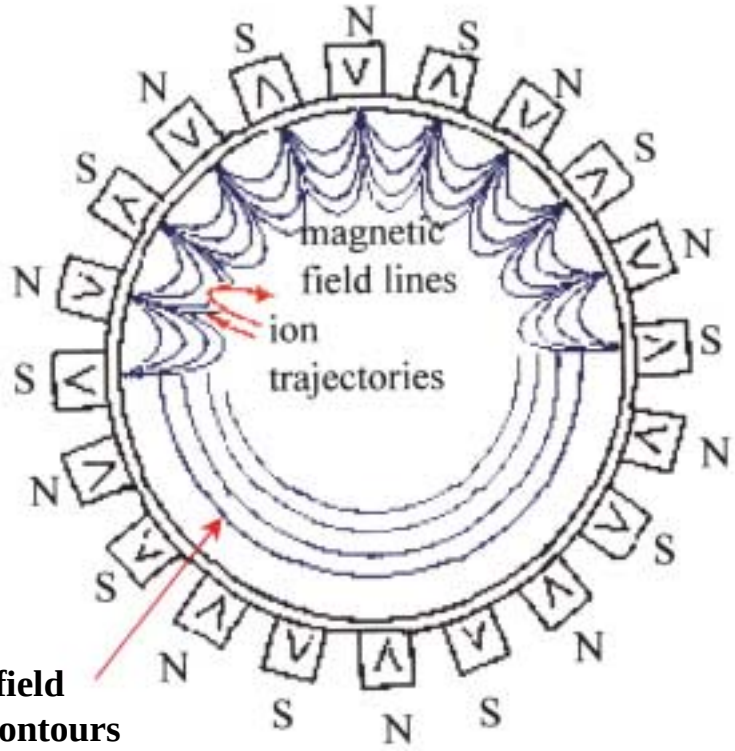
Volume Production



Surface Conversion

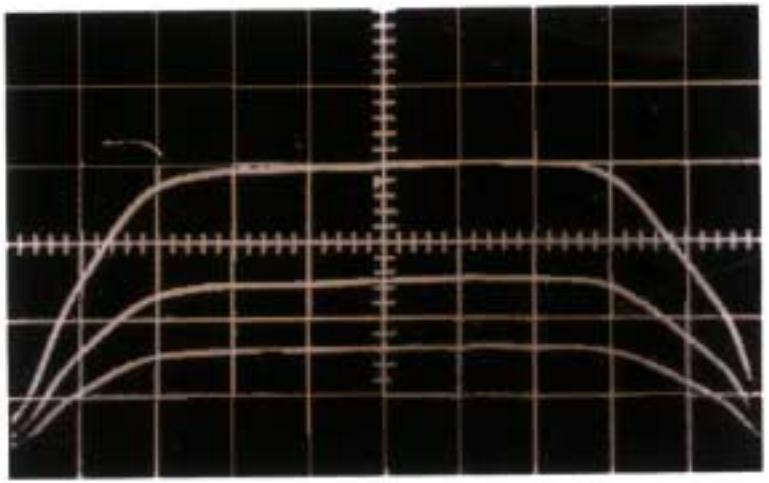


Multi-Cusp Plasma Source



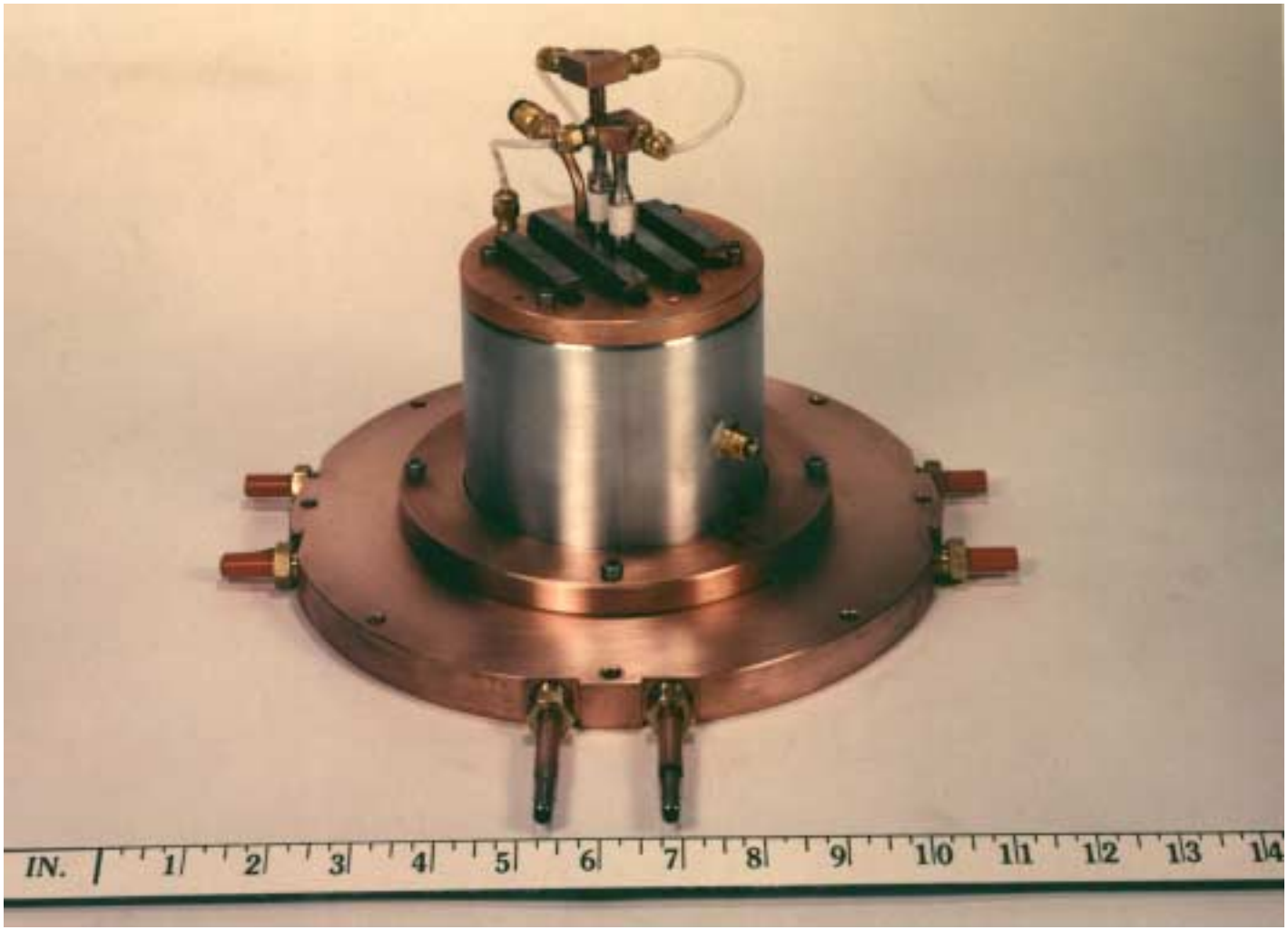
Constant field strength contours

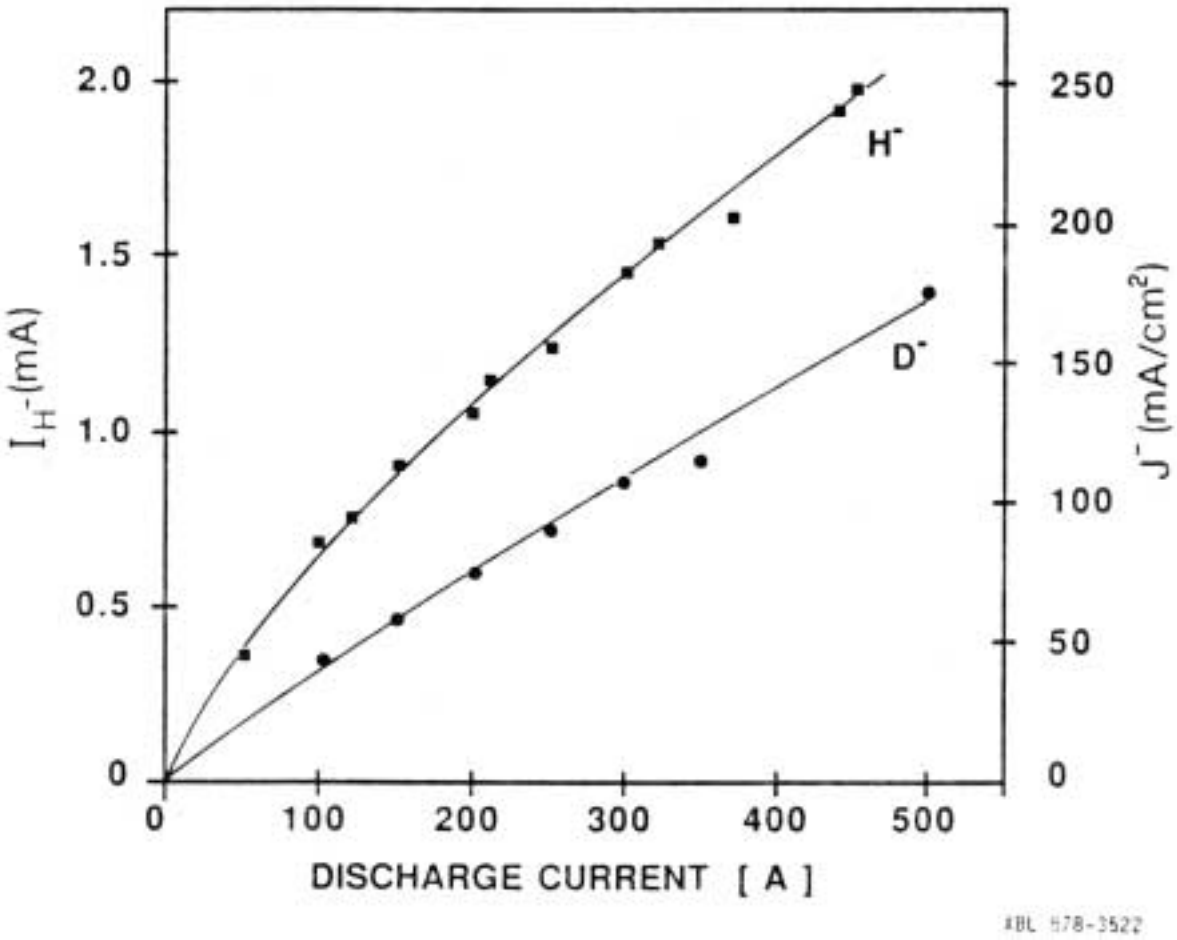
Line-cusp magnetic fields



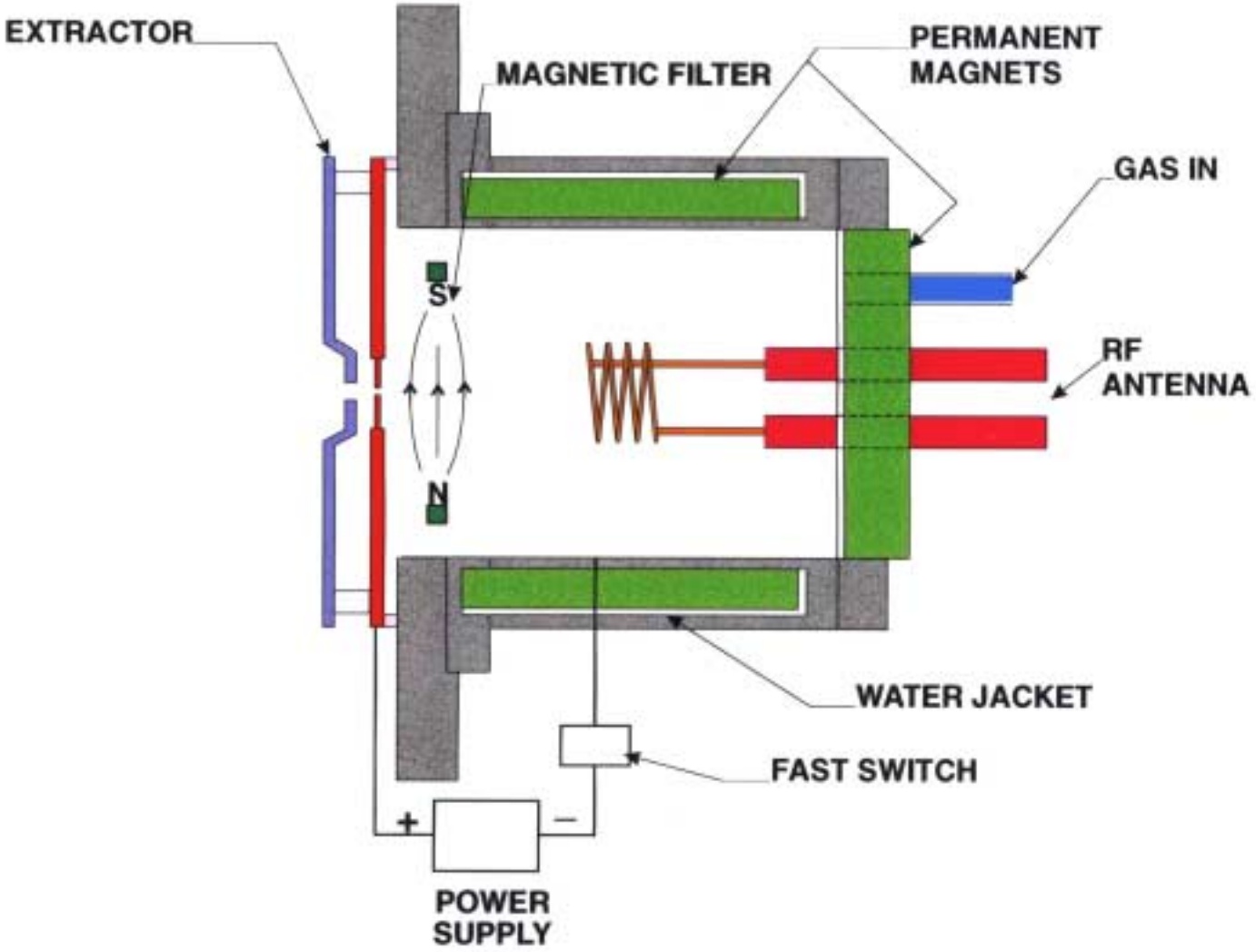
Radial plasma density profile

The 7.5-cm-diam Multicusp H^- Ion Source



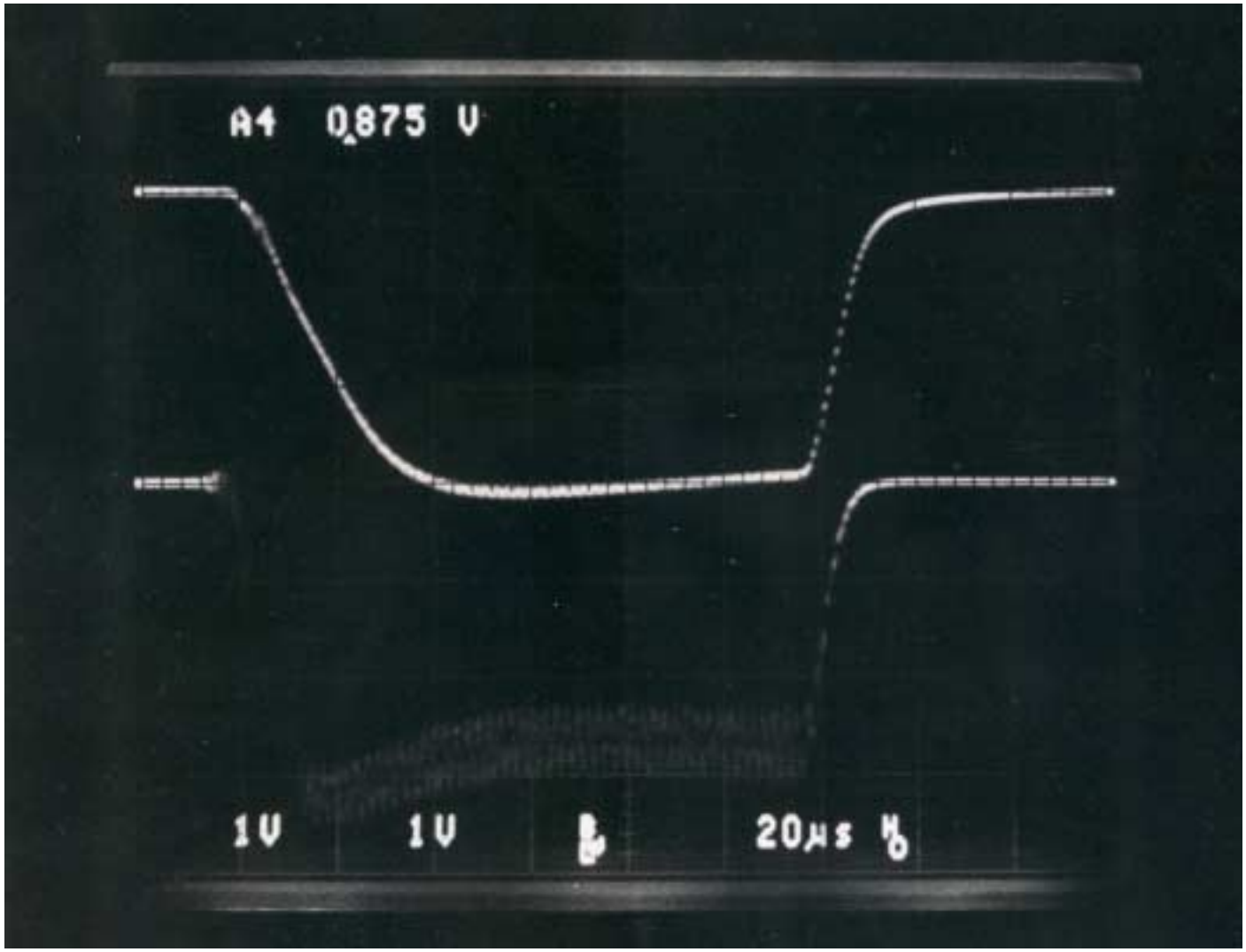

2.0
1.5
1.0
0.5
0
I_{H^-}(mA)
250
200
150
100
50
0
J^- (mA/cm^2)
H$^-$
D$^-$
0
100
200
300
400
500
DISCHARGE CURRENT [A]
XBL 878-3522

The RF-driven Multicusp Ion Source

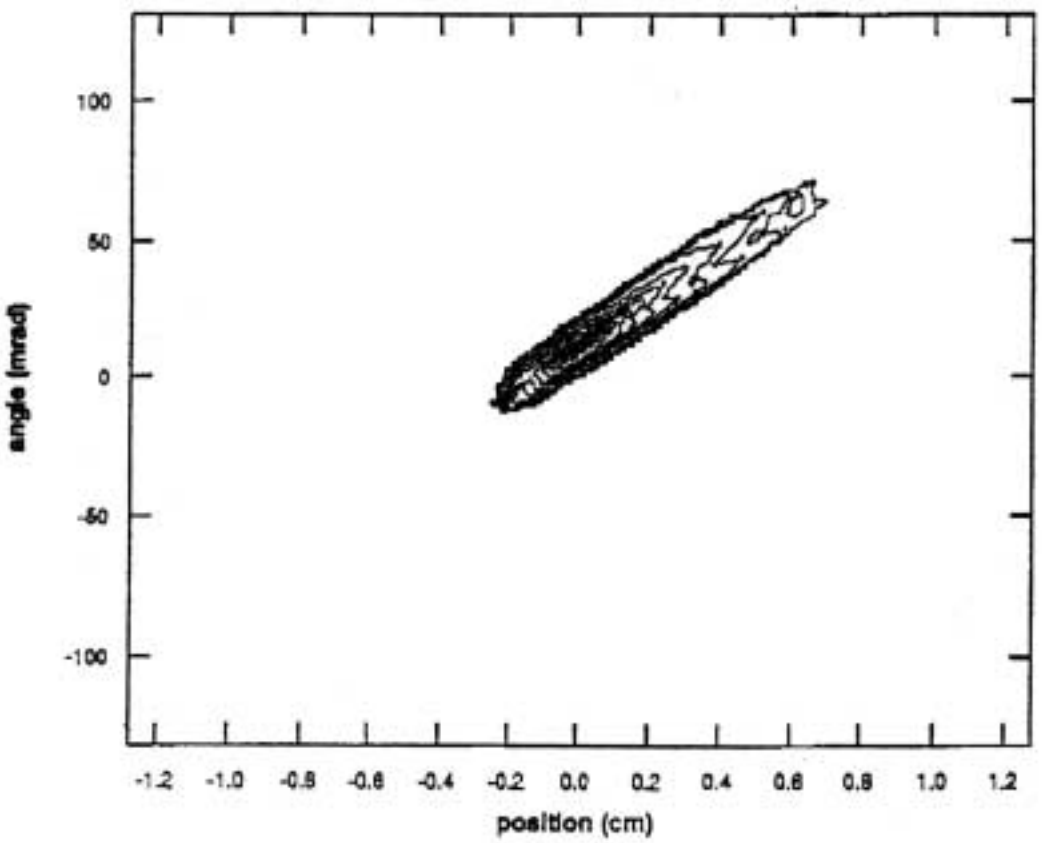


The RF-driven Multicusp Source

The H- Beam Pulse of the SSC Ion Source



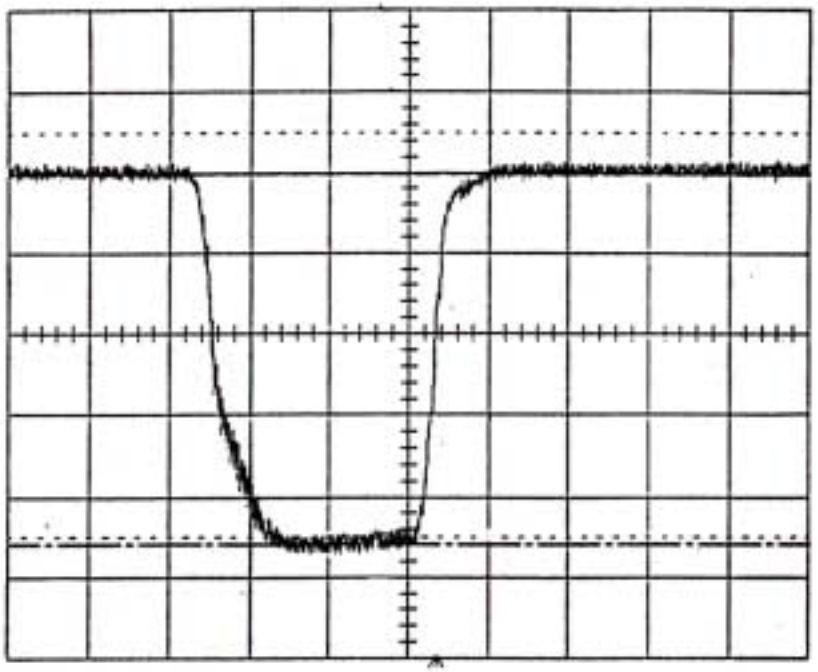
Emittance of the SSC H^- Ion Beam



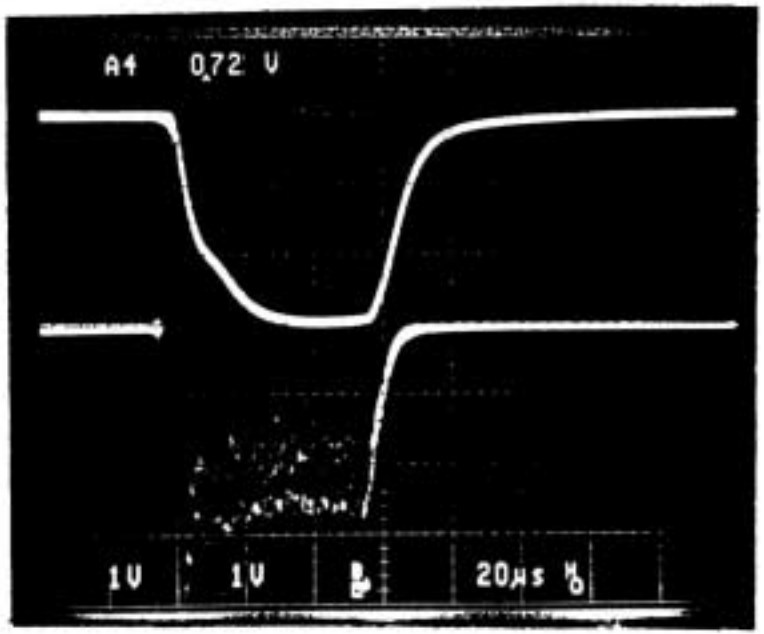
d = 9 mm
r = 3 mm
V = 35 kV
I_n = 91%
I_b = 1.0 A

ε = 0.06 π mm mr
divergence = 90 mr
diameter = 0.95 cm

H- Beam Current Pulse before and after the SSC RFQ



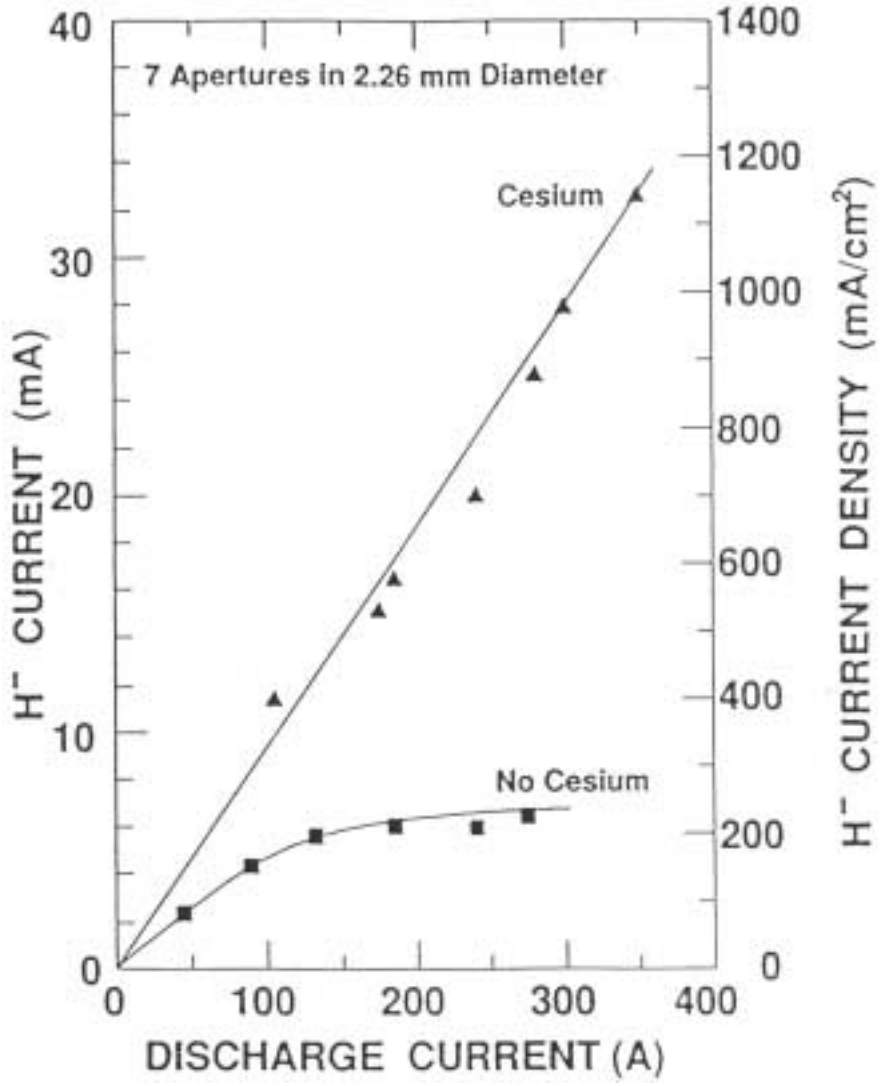
Vertical Axis : 4 mA/div
Horizontal axis : 20 μs/div

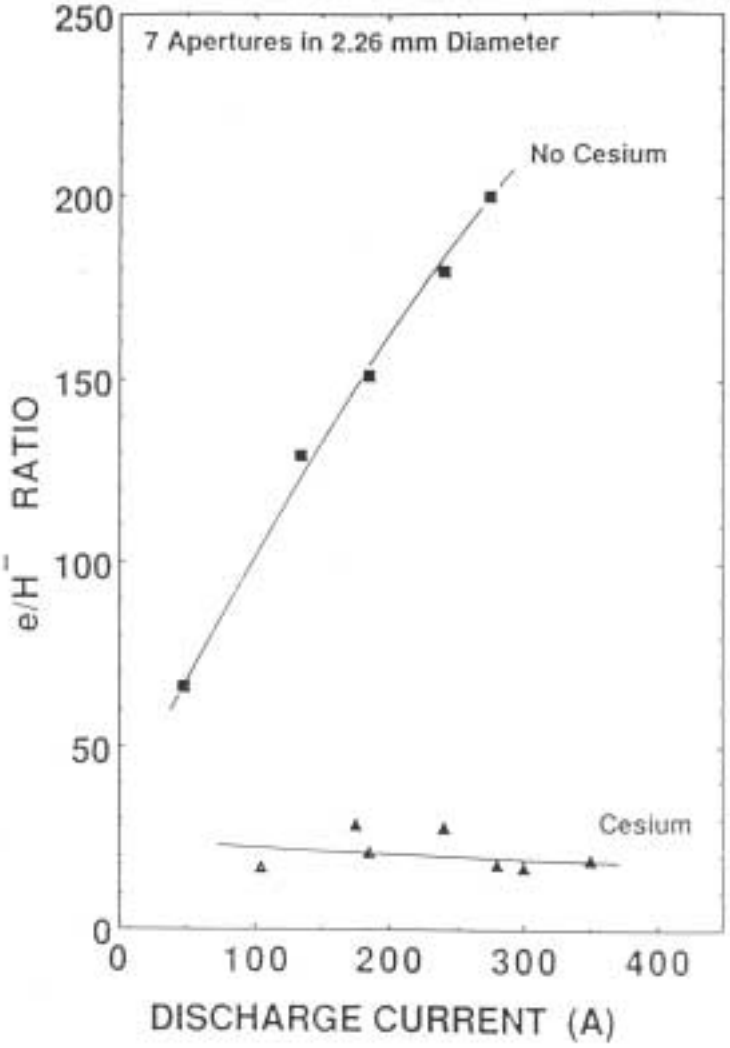


Top trace : H^- current 10 mA/div
Bottom trace : electron current 500 mA/div
Horizontal axis: 20 μs/div

SNS Ion Source Requirements

	1 MW facility	2 to 4 MW facility
Source Type	RF driven multicusp ion source, Volume produced H, Cesium enhanced, Filter magnets	
Ion	H^-	H^-
Current [mA]	35	70
Emittance [π mm mrad, norm rms]	0.15	0.2
RF frequency [MHz]	2	2
Plasma initiation	flash lamp through quartz window	
Electron suppression	magnets in extraction plate, complete deflection	
Final H- energy [keV]	65	65
Duty factor [%]	6.2	6.2
Chopping frequency [MHz]	1.188	1.188
Source Pressure [mTorr]	10	10
Lifetime [month]	1	1


7 Apertures in 2.26 mm Diameter
Cesium
No Cesium
H⁻ CURRENT (mA)
H⁻ CURRENT DENSITY (mA/cm²)
DISCHARGE CURRENT (A)
0
10
20
30
40
0
200
400
600
800
1000
1200
1400
0
100
200
300
400


7 Apertures in 2.26 mm Diameter
No Cesium
Cesium
e/H⁻ RATIO
DISCHARGE CURRENT (A)
250
200
150
100
50
0
0
100
200
300
400

RF H^- Source Operation Issues

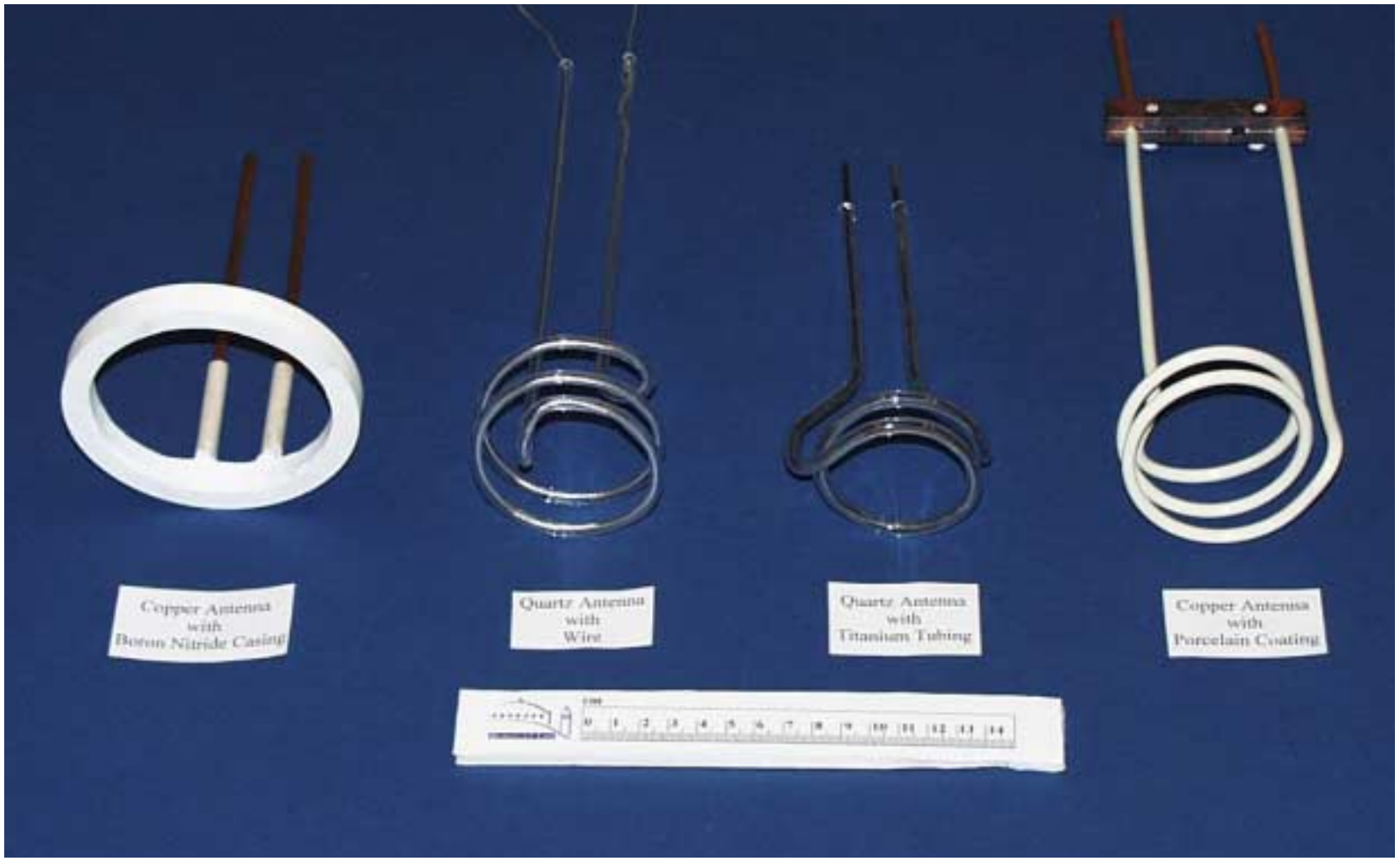
- RF power supply
  - 2 MH_z or 13.5 MH_z
- Antenna coating
  - porcelain, wire inside quartz tubing or metal tubing inside quartz tubing
- Plasma ignition schemes
  - filament, laser, flash lamp, dual-frequency
- Cesium enhancement
  - SAES getters, oven

Antenna Coating

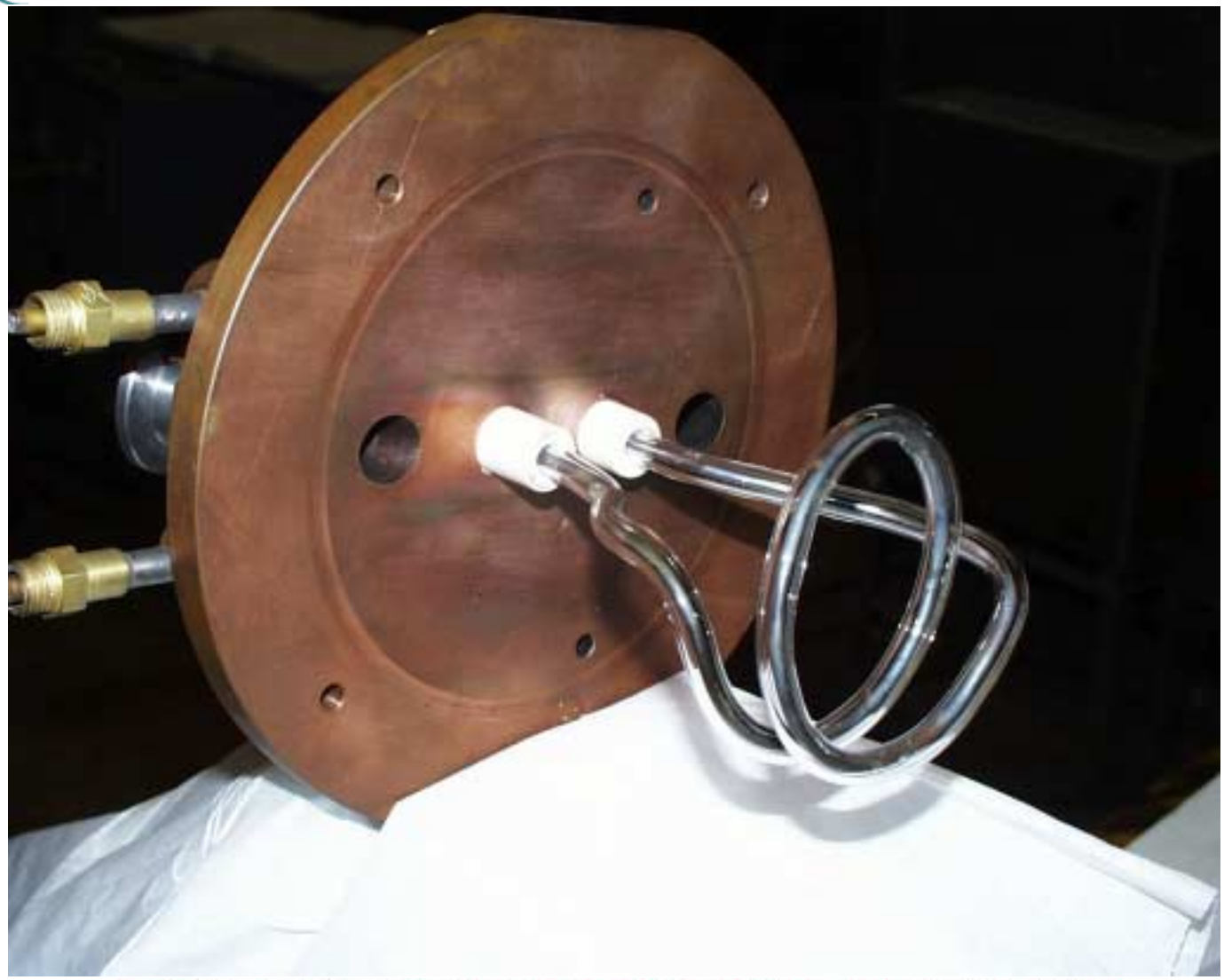
A good antenna coating is needed for high power cw or pulse source operations

- to withstand a high potential gradient between the plasma and the antenna
- to minimize the sputtering of antenna material
- to increase the efficiency of the ion source

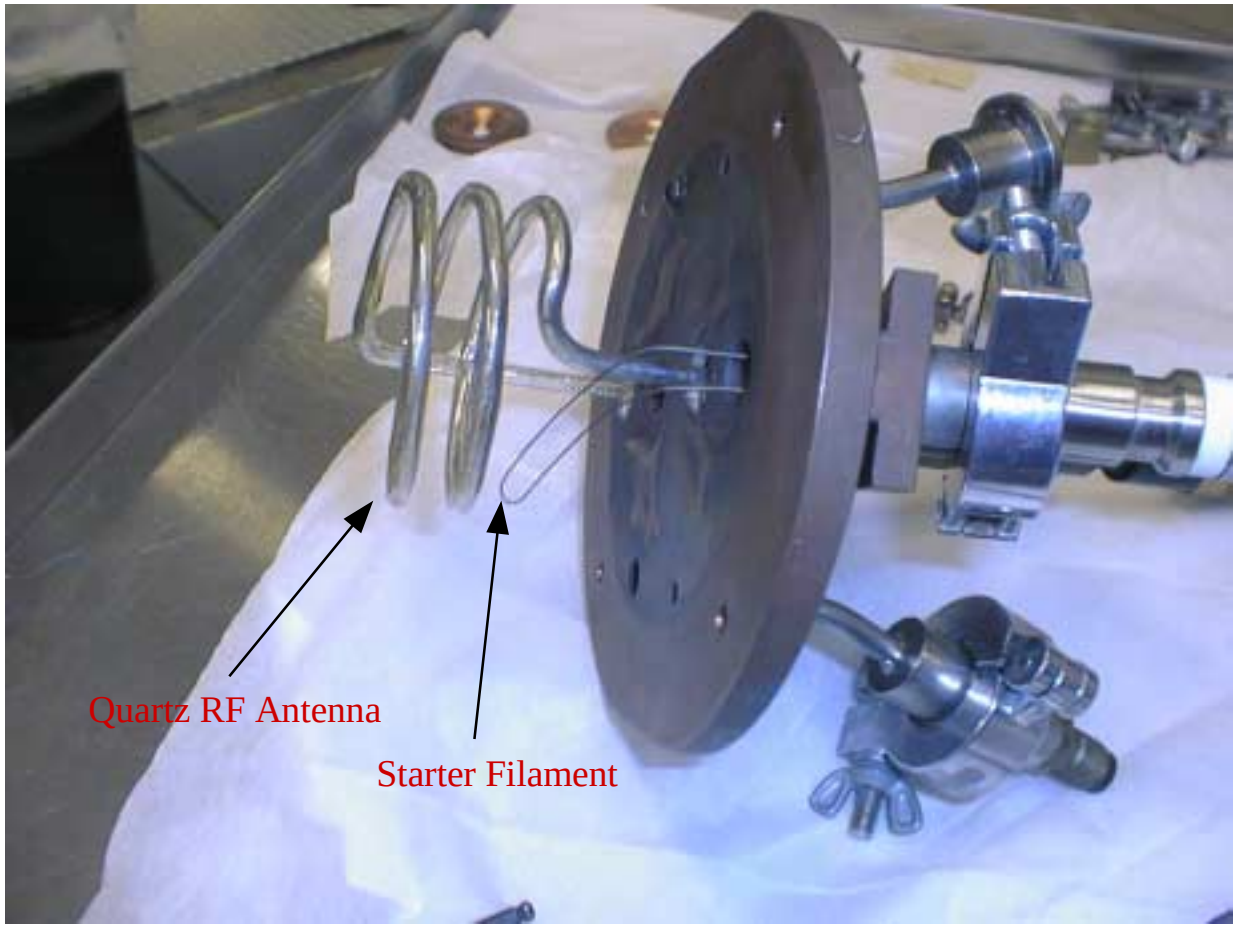
Different Antennas Used in the Life-Time Tests



Quartz Tube Antenna with Titanium Tube Inside

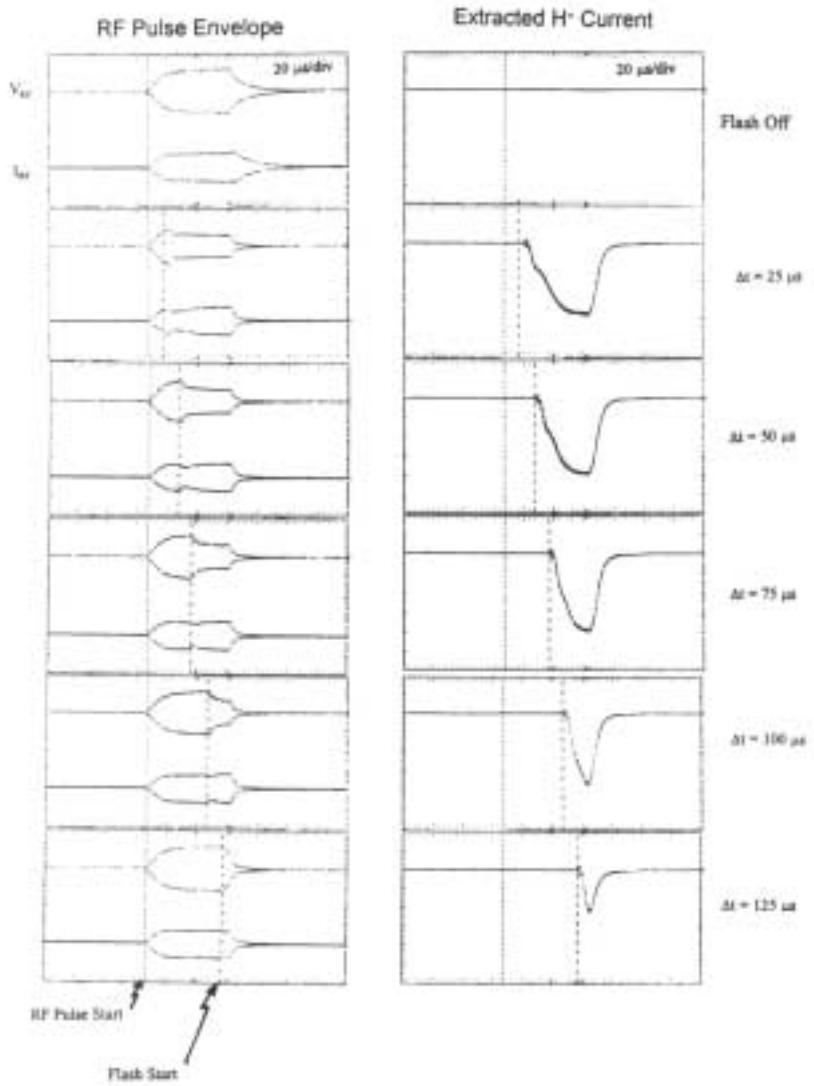


Starter Filament

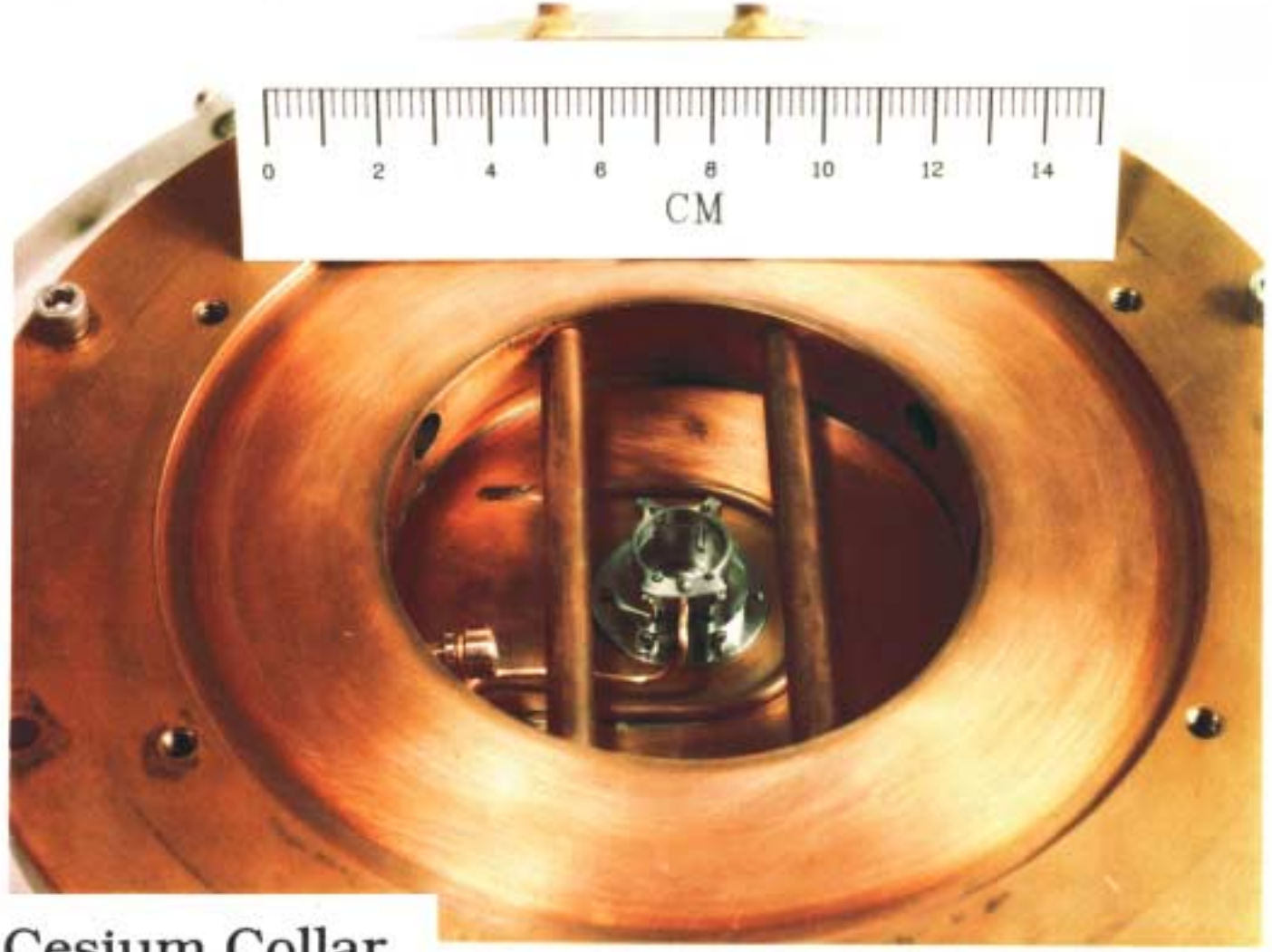


Ignition of the RF Plasma with a Laser Beam

RF Plasma Ignition with Photons



The Collar with Cesium Dispensers



Cesium Collar

Electron Dumping and Beam Chopping

- Surface Conversion Source

  Electron dumping - low electron content

  H^- beam chopping - by "kicking" the H^- beam inside the source

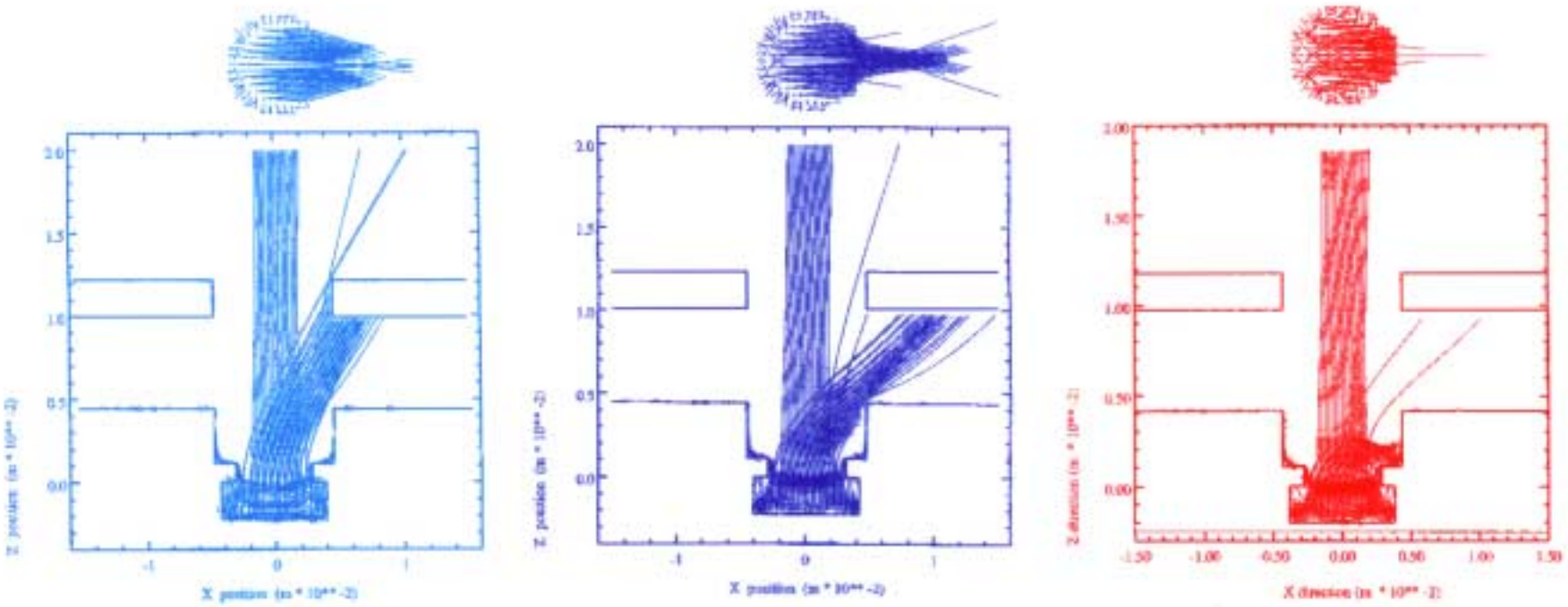
- Volume Production Source

  Electron dumping - strong magnetic field at source exit

  - micro-channel to filter the electrons

  H^- beam chopping - modulating the extraction voltage at the micro-channel electrodes

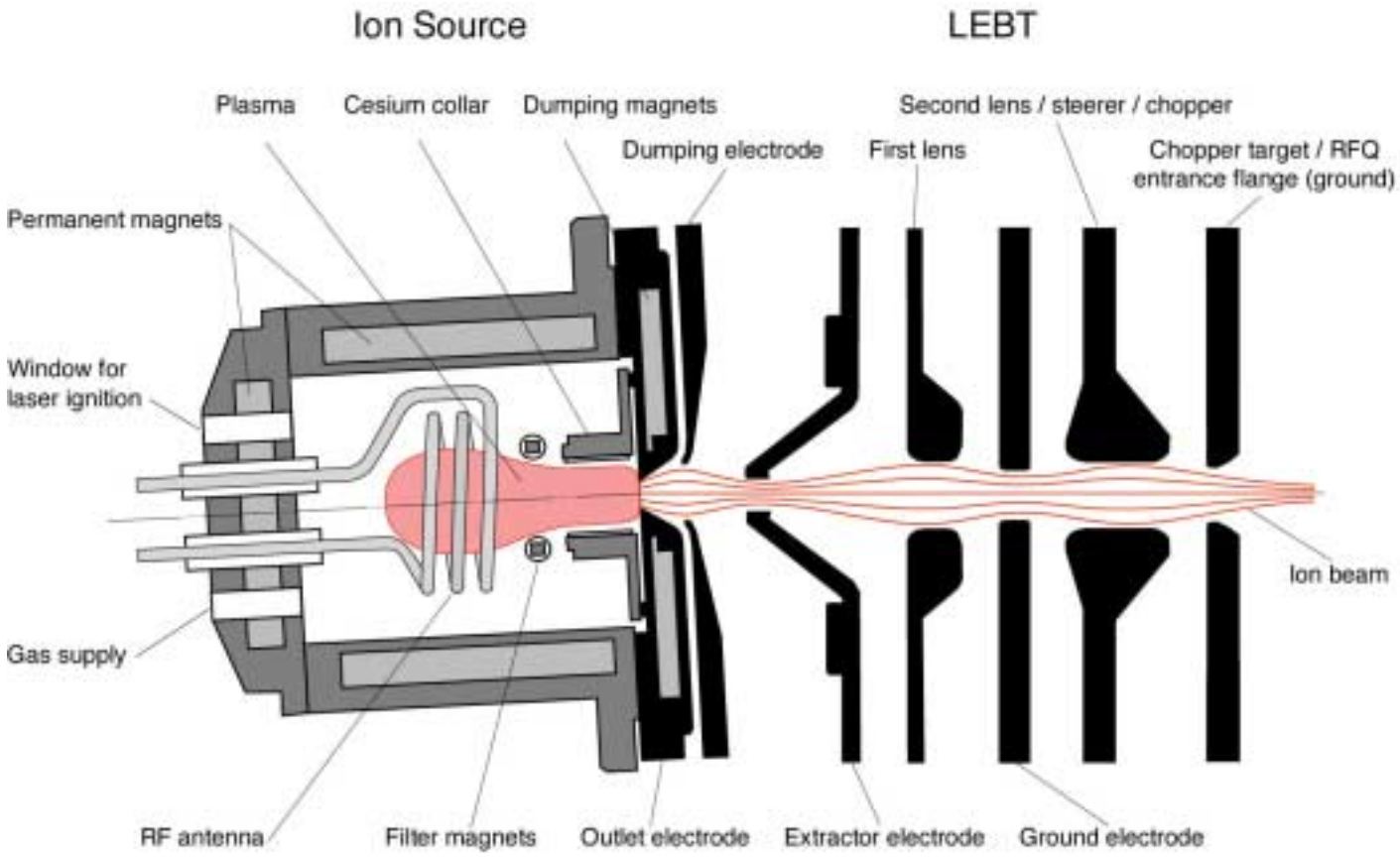
Electron Removal (Argus Code Computation)



250 Gauss 400 Gauss 650 Gauss

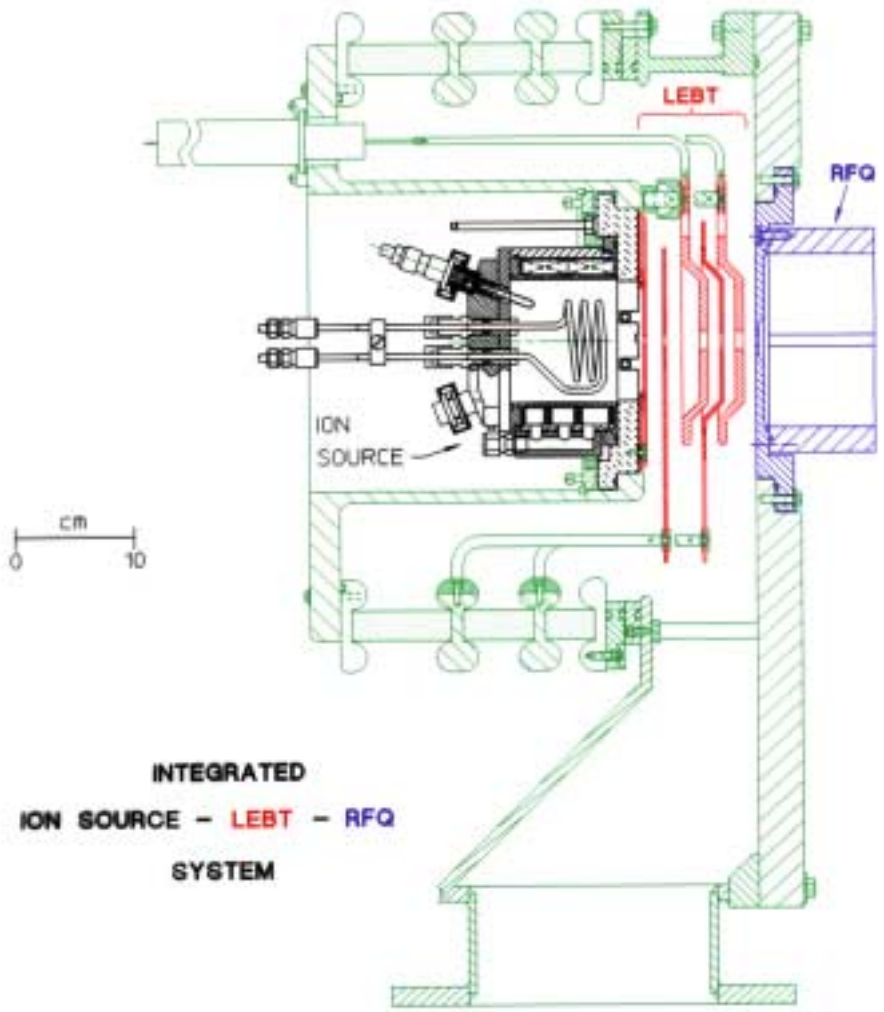
transverse magnetic field

Ion Source and LEBT Schematic



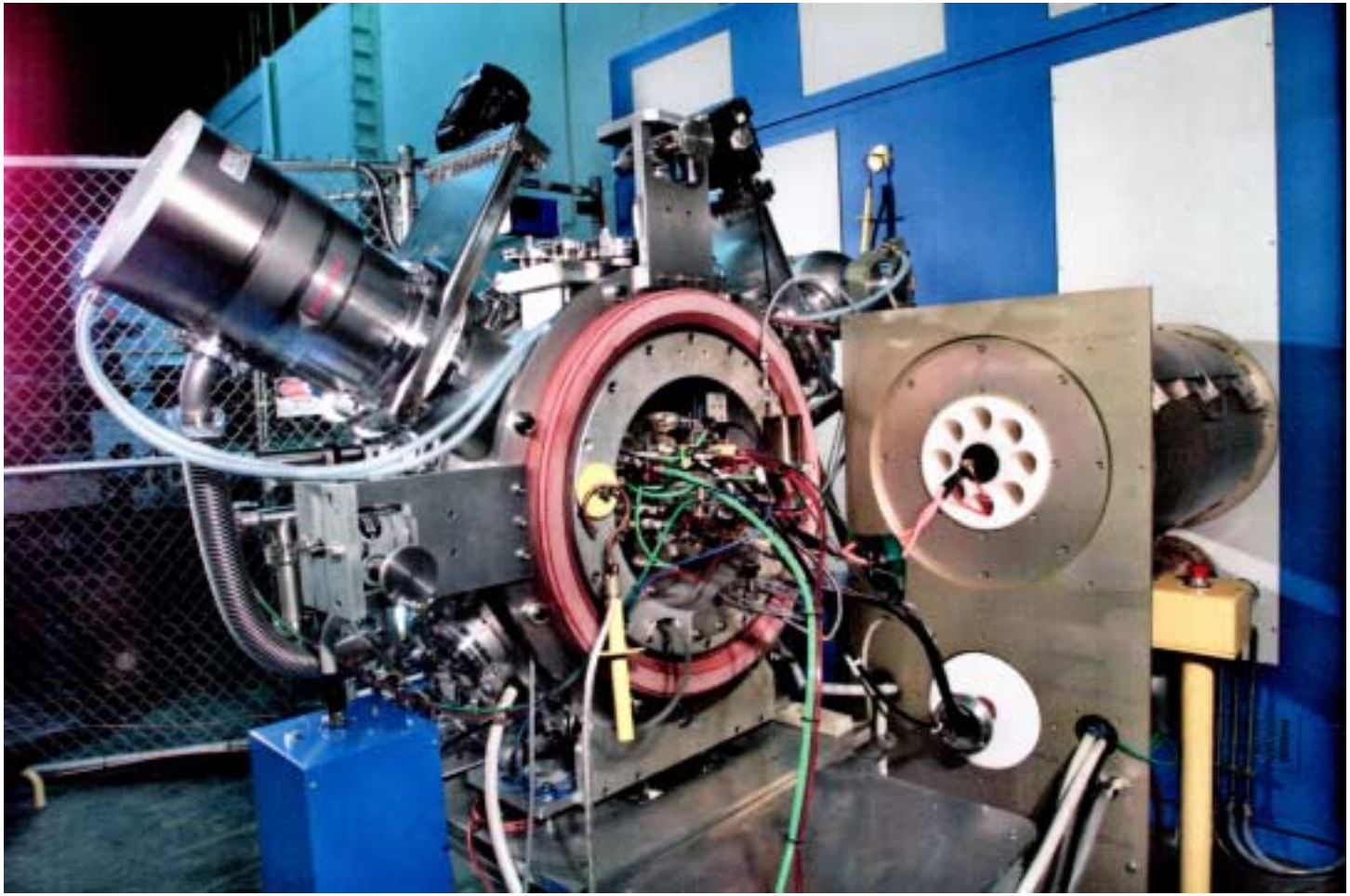
The ion source with outlet and dumping electrodes is tilted by 3 deg. with respect to the LEBT axis
Some magnet orientations are rotated into the viewing plane of this illustration
The shape of the beam envelope is exaggerated for emphasis

H^- Source and LEBT System

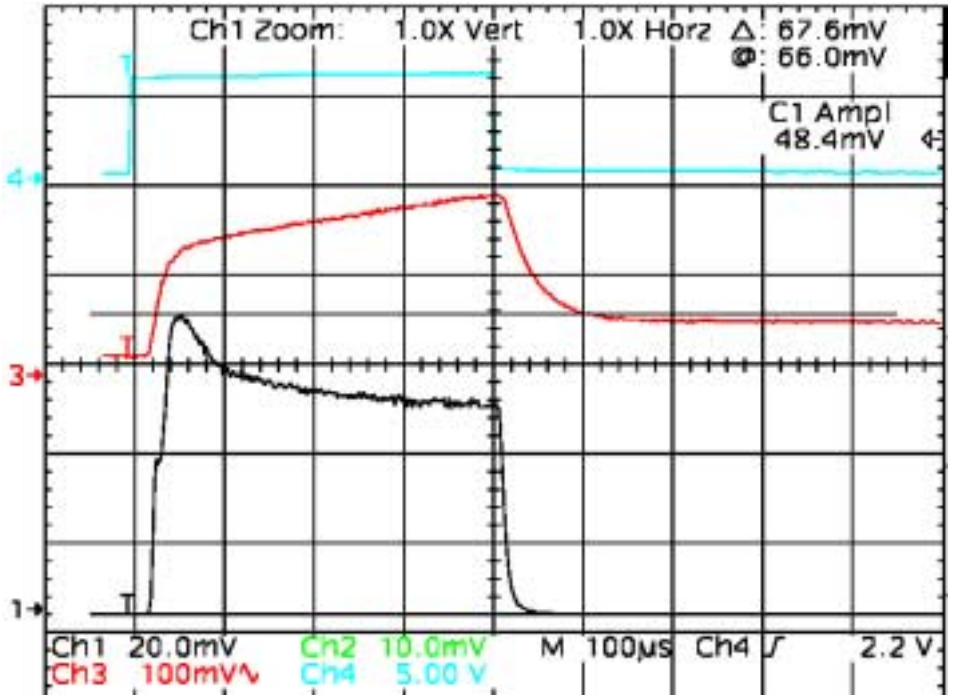


The SNS H^- LEBT System

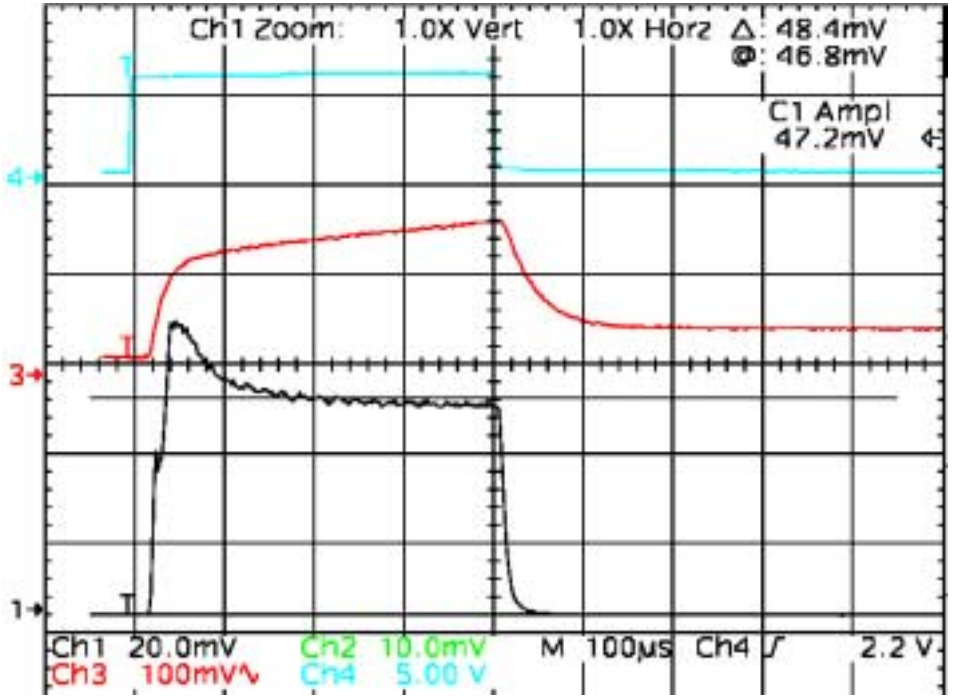
The SNS H^- Ion Source



Ion-Source/LEBT Beam Current

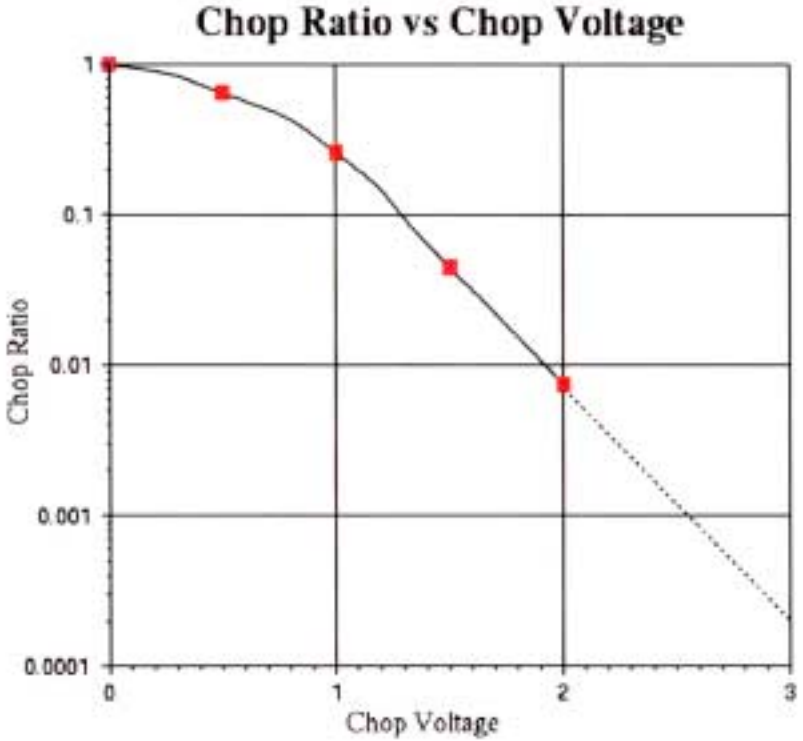


68 mA peak current



50 mA average current

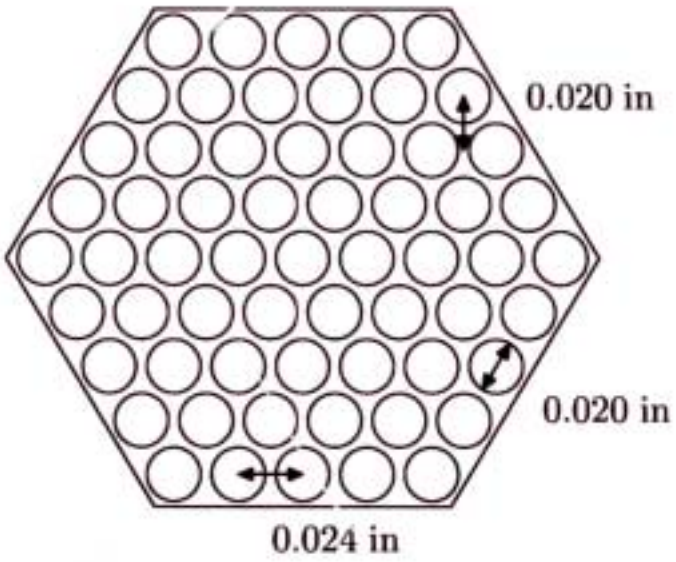
Chop Depth vs. Chop Voltage

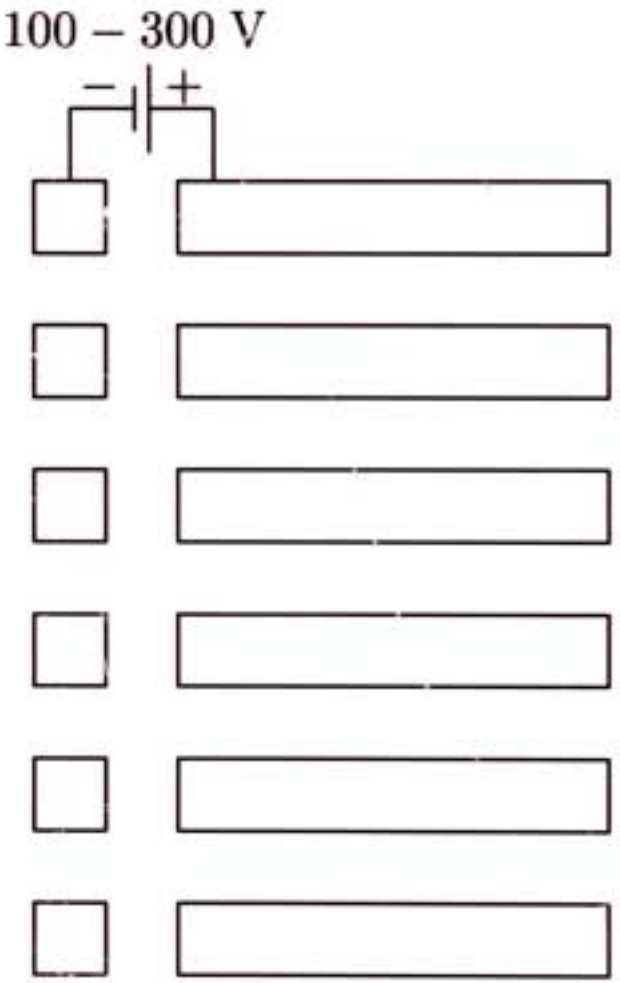


- Chop voltage applied across deflector quadrants
- Most beam lost on LEBT diagnostic device
- Remaining beam lost in RFQ
- 2.5 kV point recorded as zero
- Easily exceeds requirements for LEBT chopper
- Guaranteed performance with LEBT and MEBT choppers is an off/on ratio of 10^{-4}.

Electron Filter for the Volume H$^-$ Source

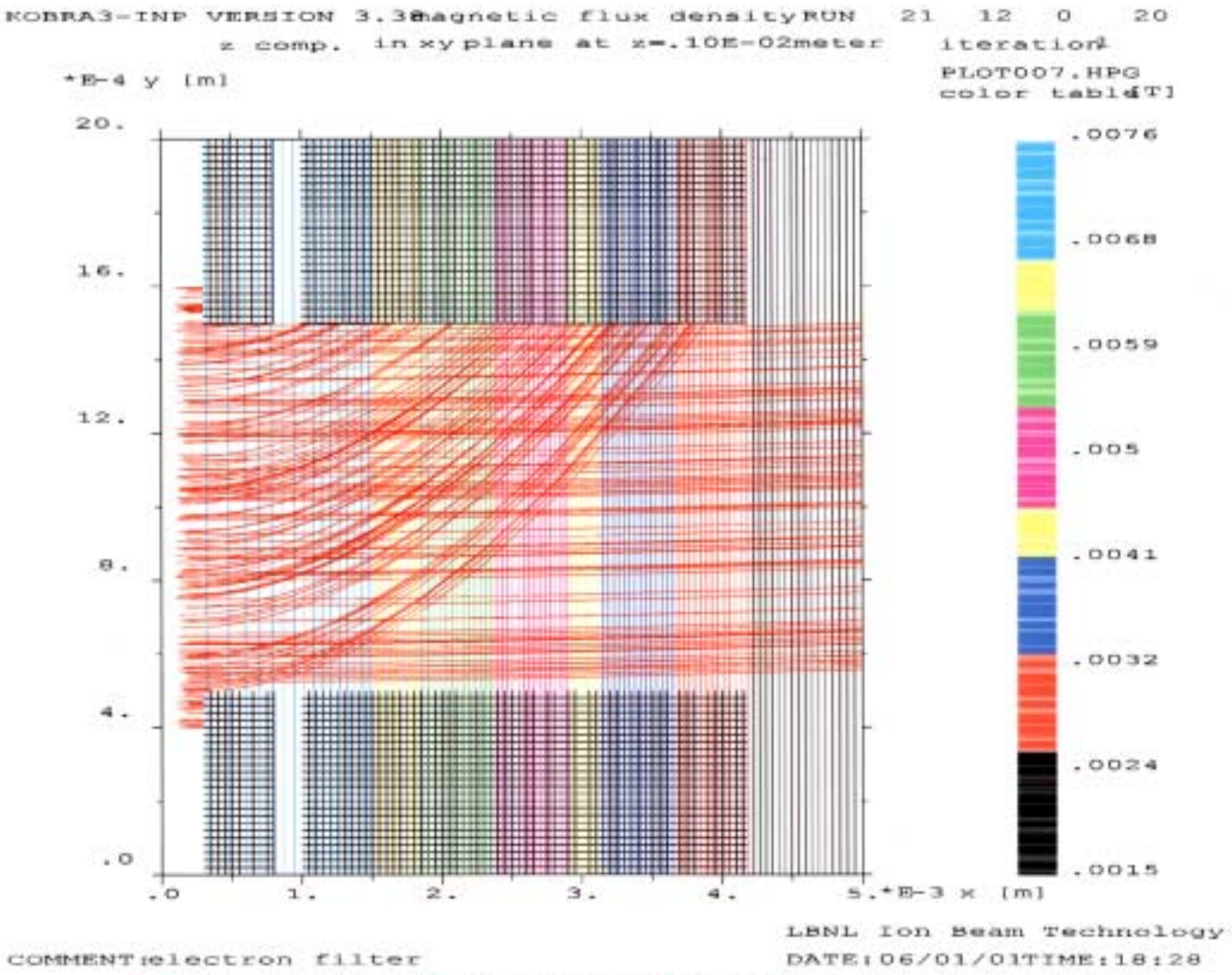
The Setup



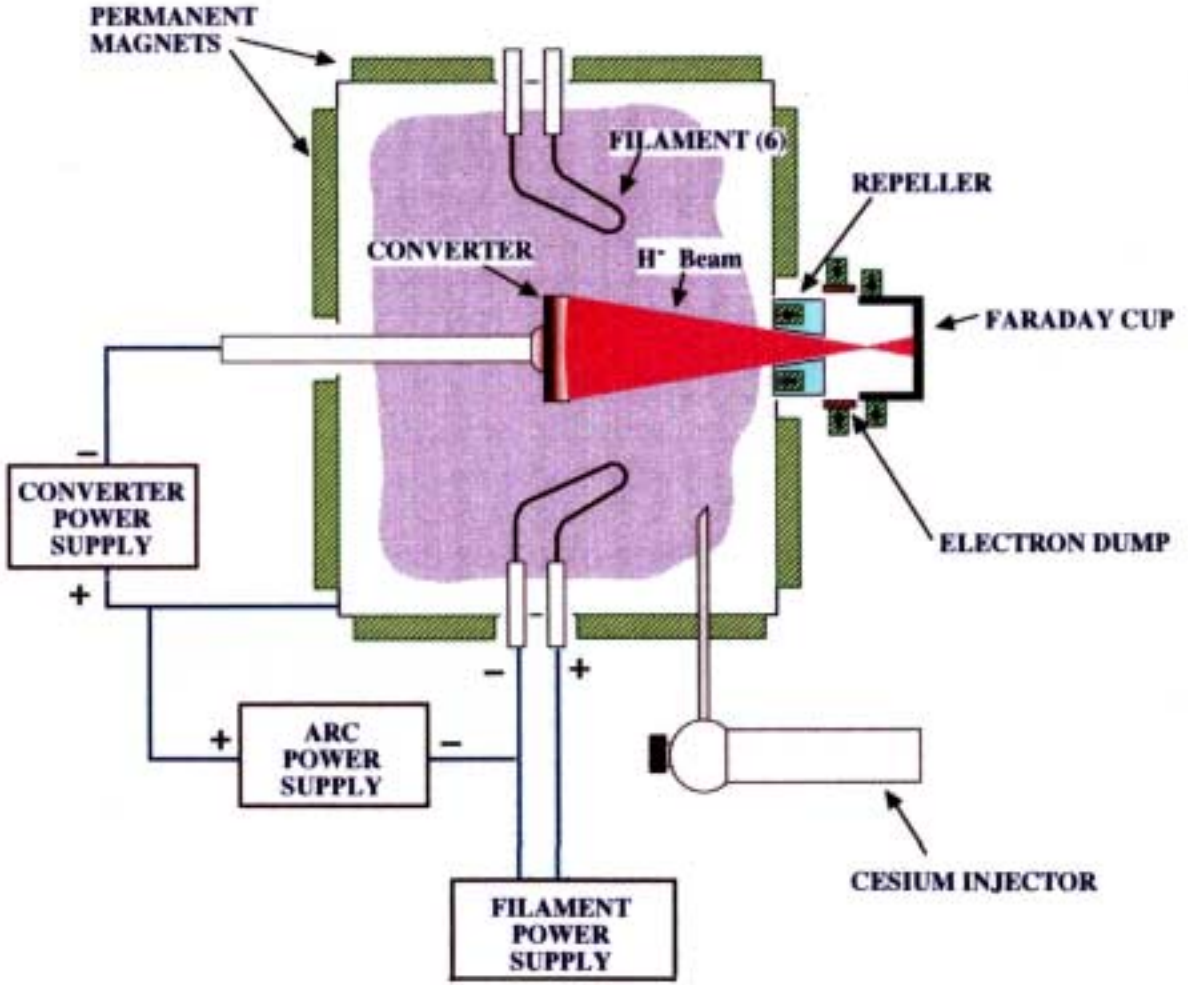


$$T = \frac{F_{\text{holes}}}{F_{\text{hex}}} \approx 68.3\%$$

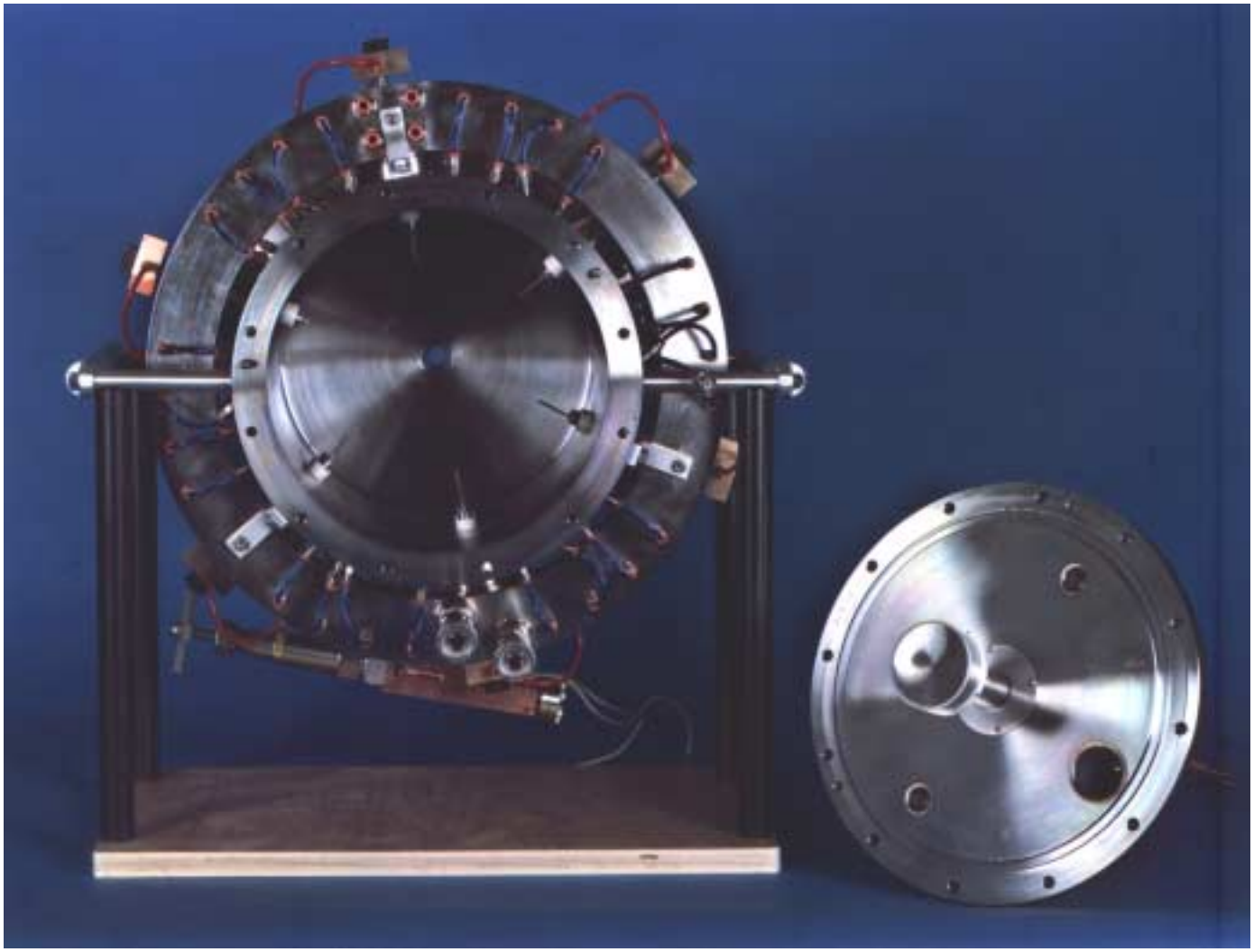
H^- and Electron Trajectories



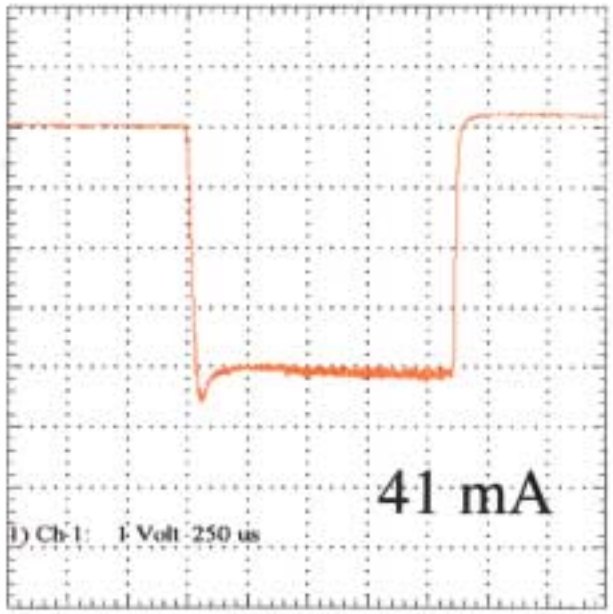
Surface-conversion Multicusp Ion Source Schematic

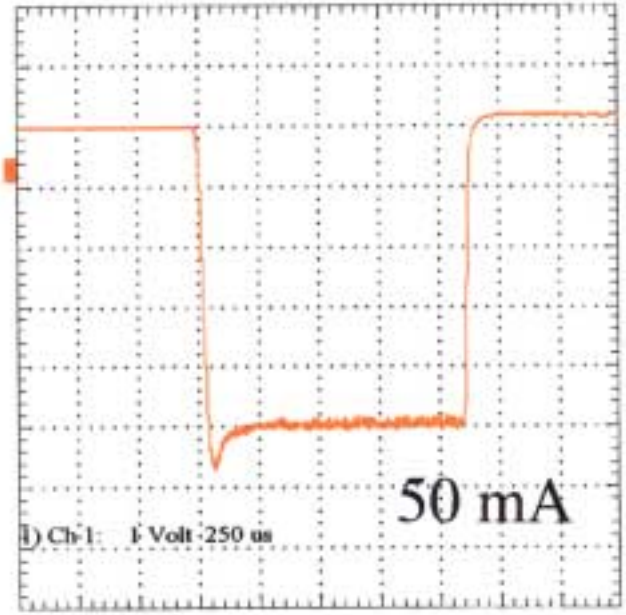


The LANSCE Surface Conversion H^- Source



LANSCE Prototype Source Scope Traces



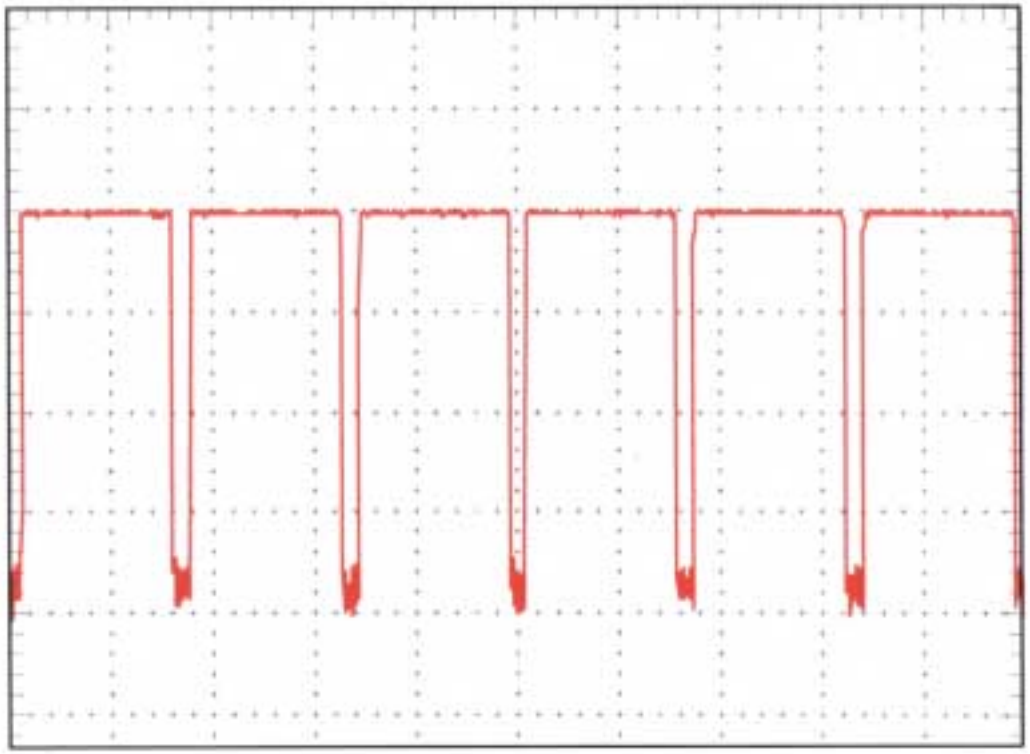


H- Faraday Cup Signal 10 mA/V

Discharge 80 V, 74 A
Converter 300V, 3.1A
Source Pressure 1.1 mT

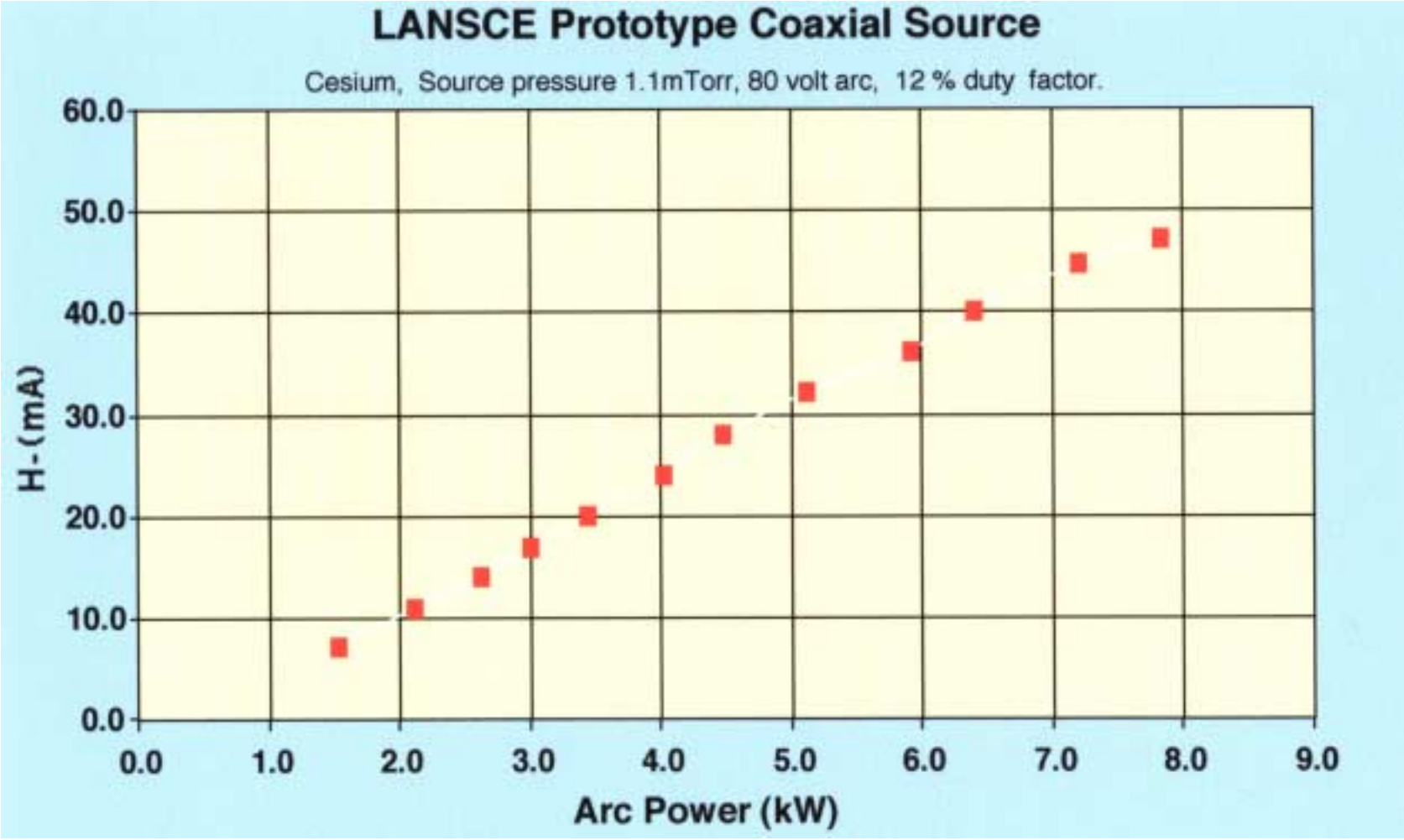
Discharge 80 V, 100 A
Converter 300V, 3.6 A
Source Pressure 1.1 mT

LANSCE Ion Source 12 % Duty Factor

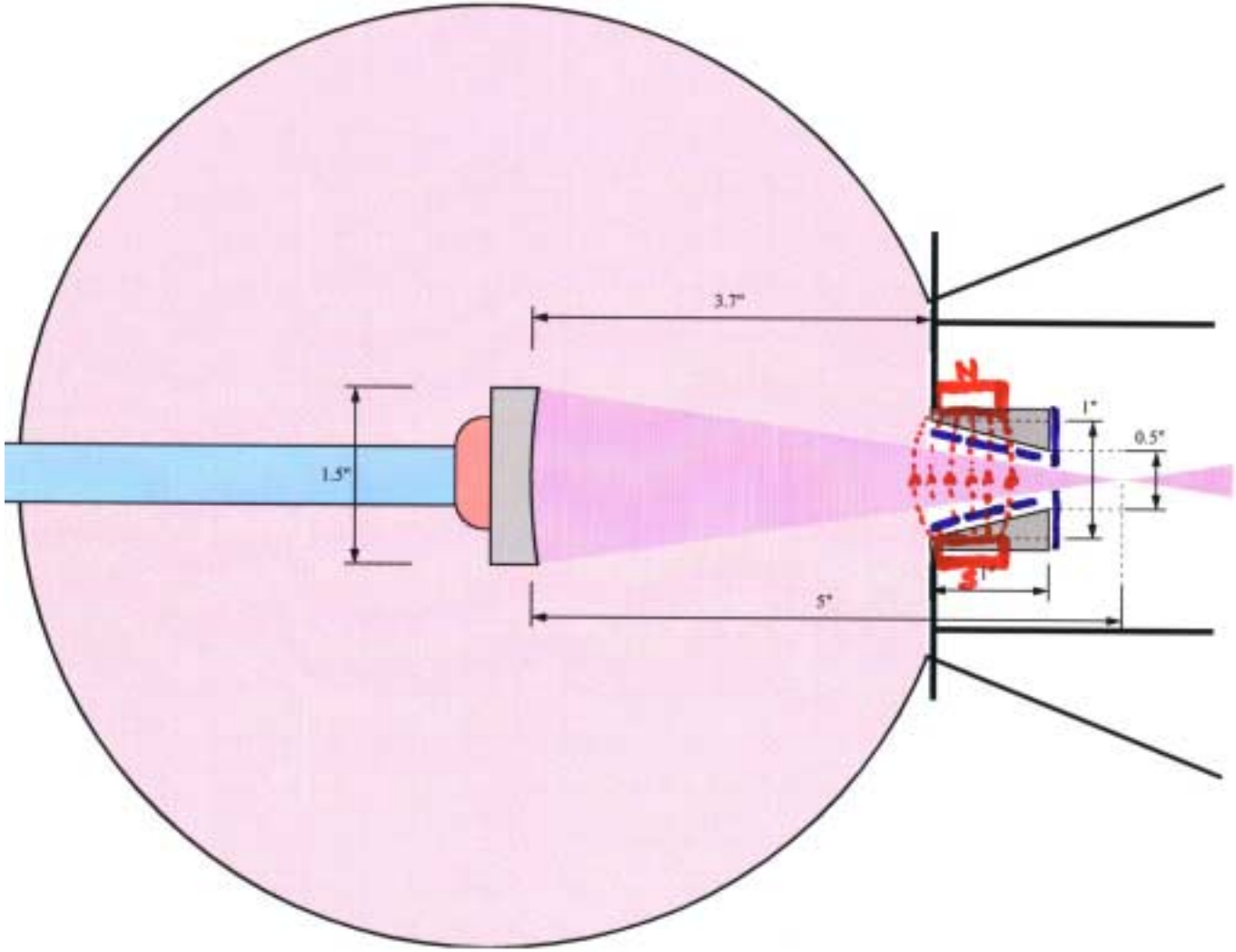


Y Scale 10 mA/div
Time Base 5 msec/div

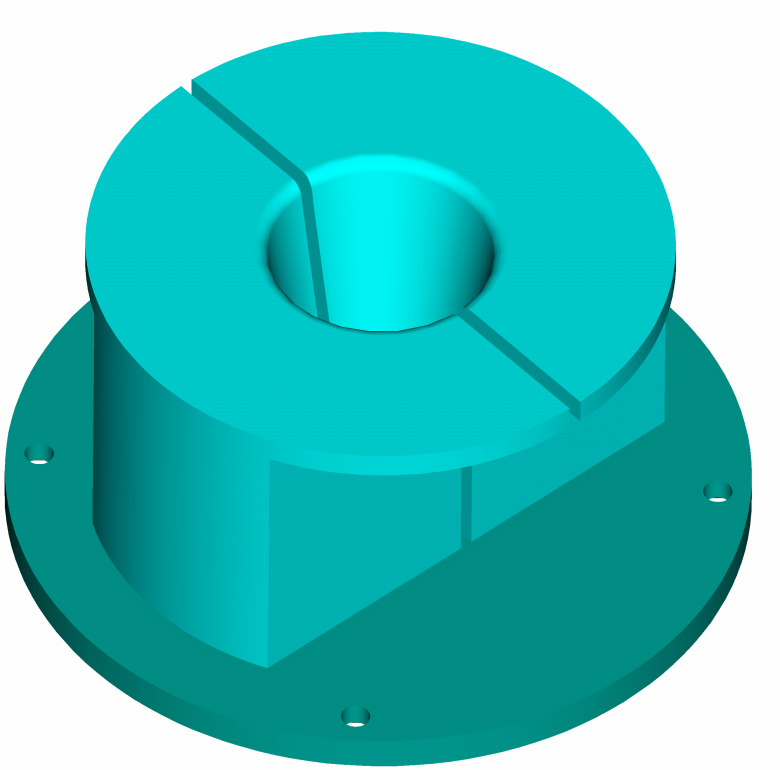
LANSCE Prototype Source Data



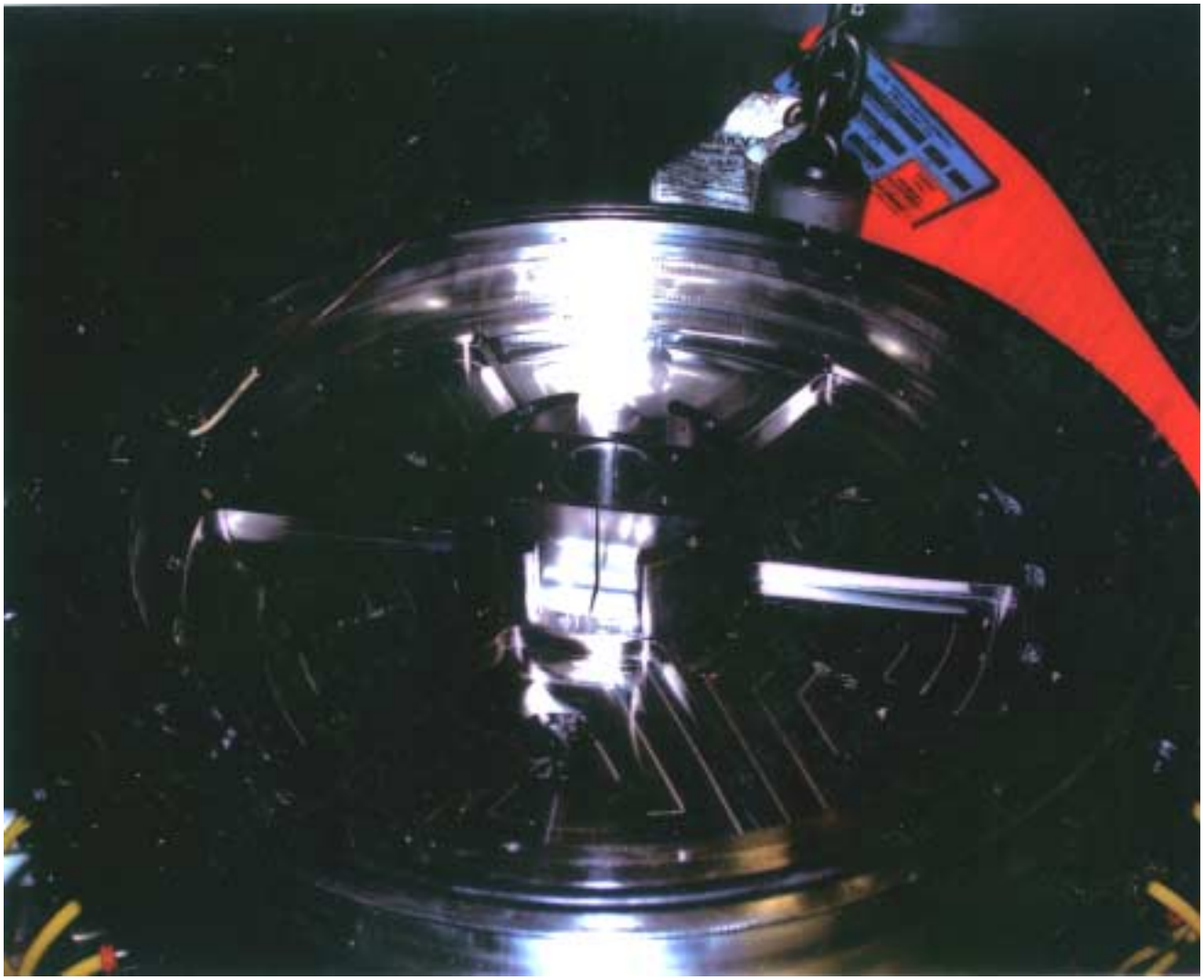
Interior of LANSCE Source with Cone Aperture



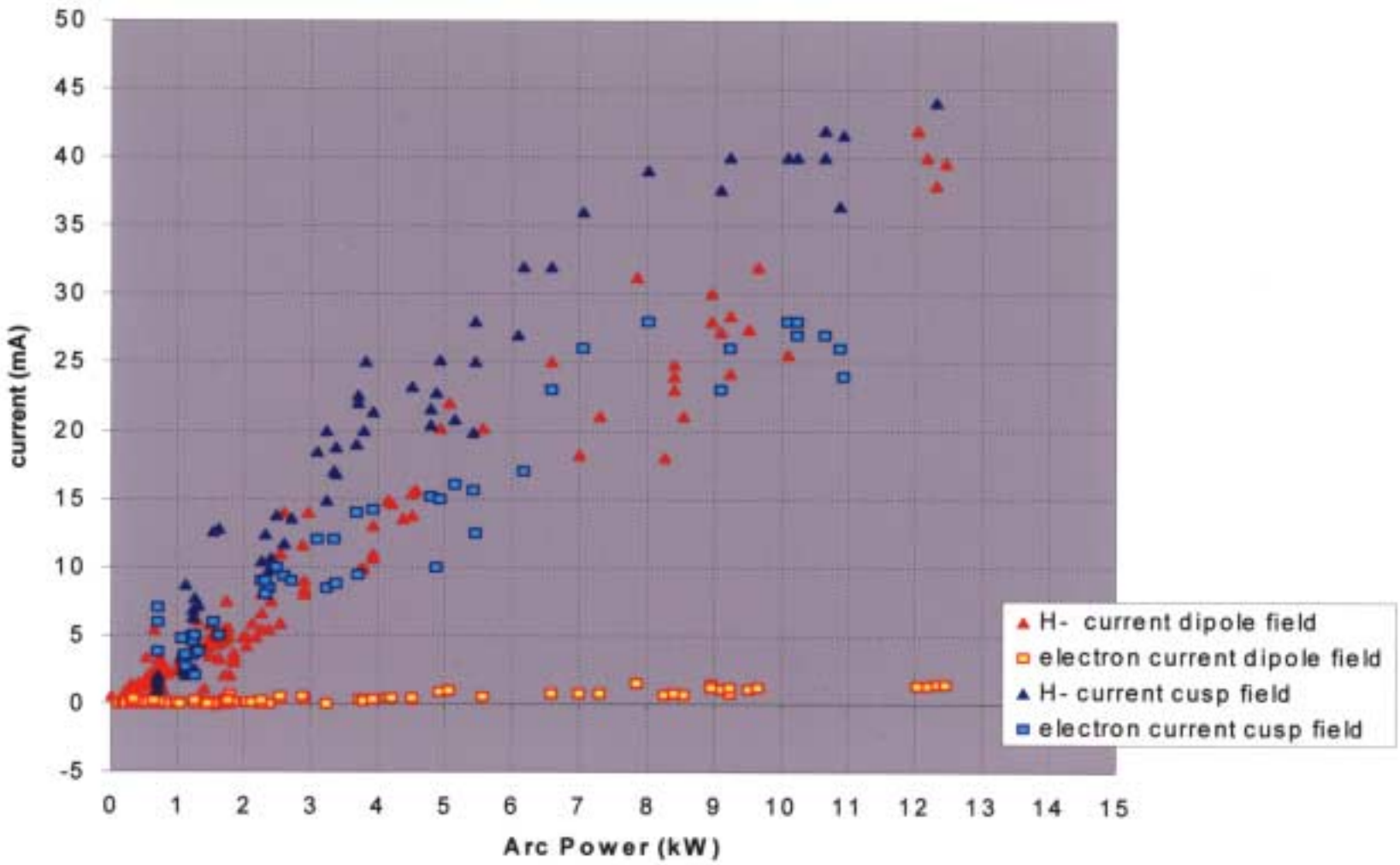
LANSCE H^- Split Repeller



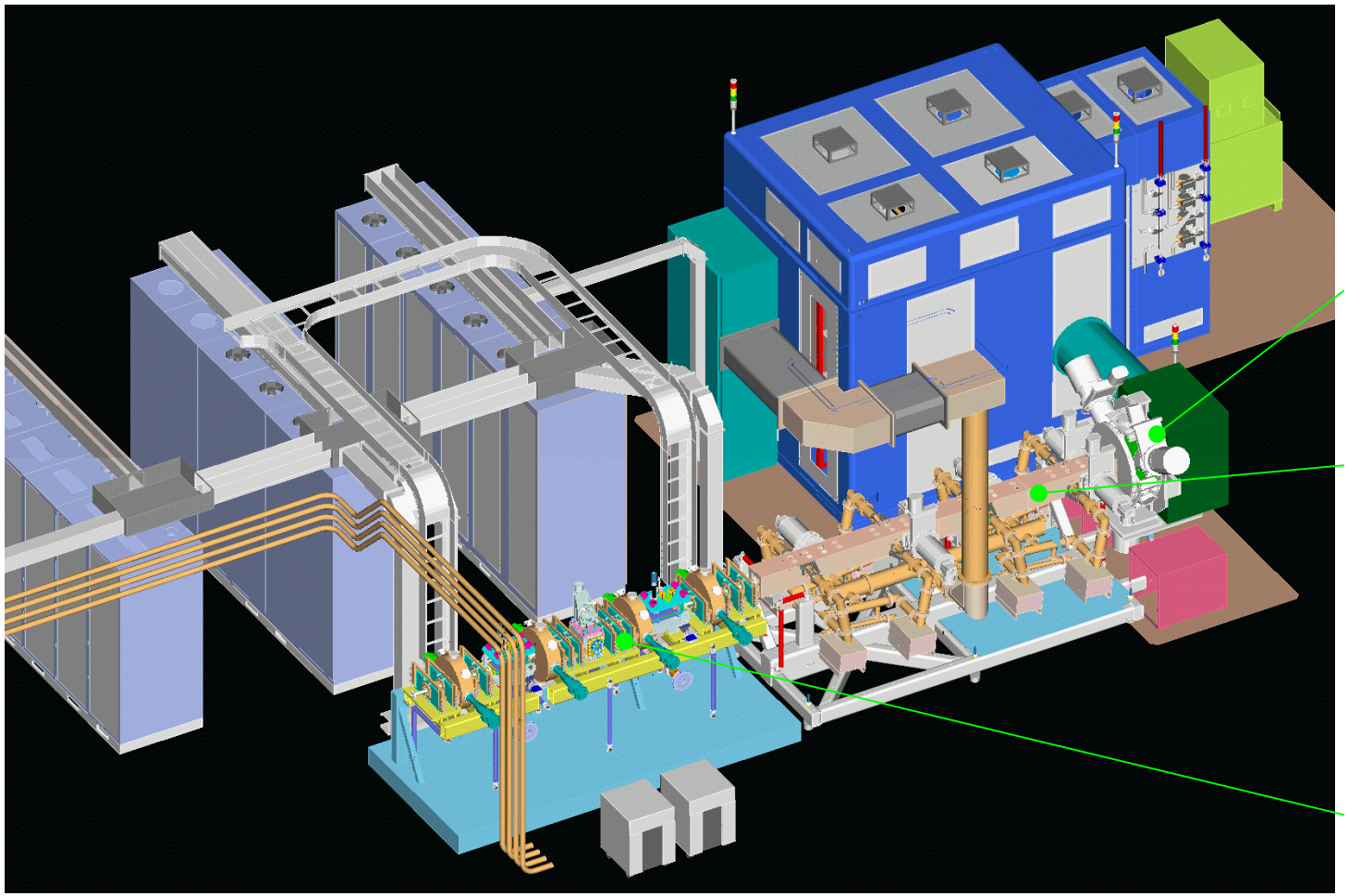
H^- Split Repeller Structure



LANSCE Repeller Upgrade



Front-End Systems: Function



Ion Source/LEBT

Create 50-mA H^- ion beam

RFQ

Accelerate beam to 2.5 MeV

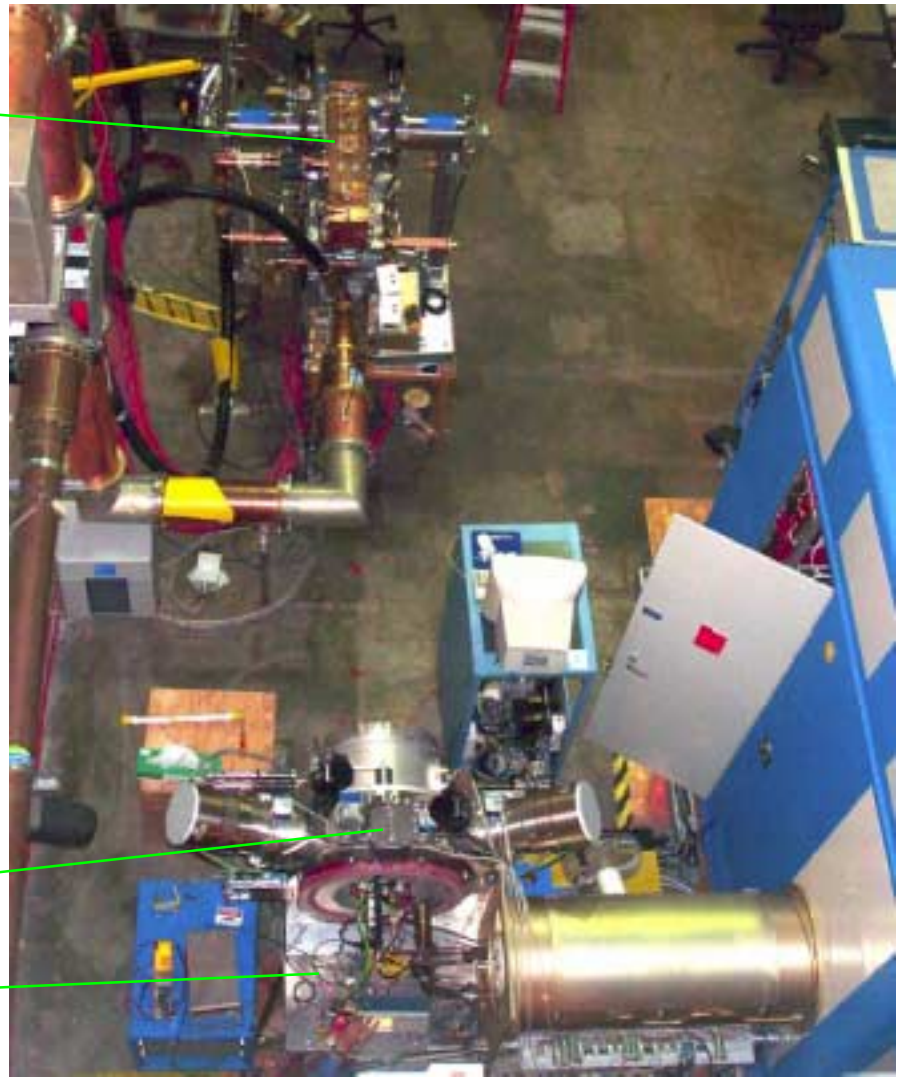
LEBT/ MEBT

Chop beam into mini-pulses

MEBT

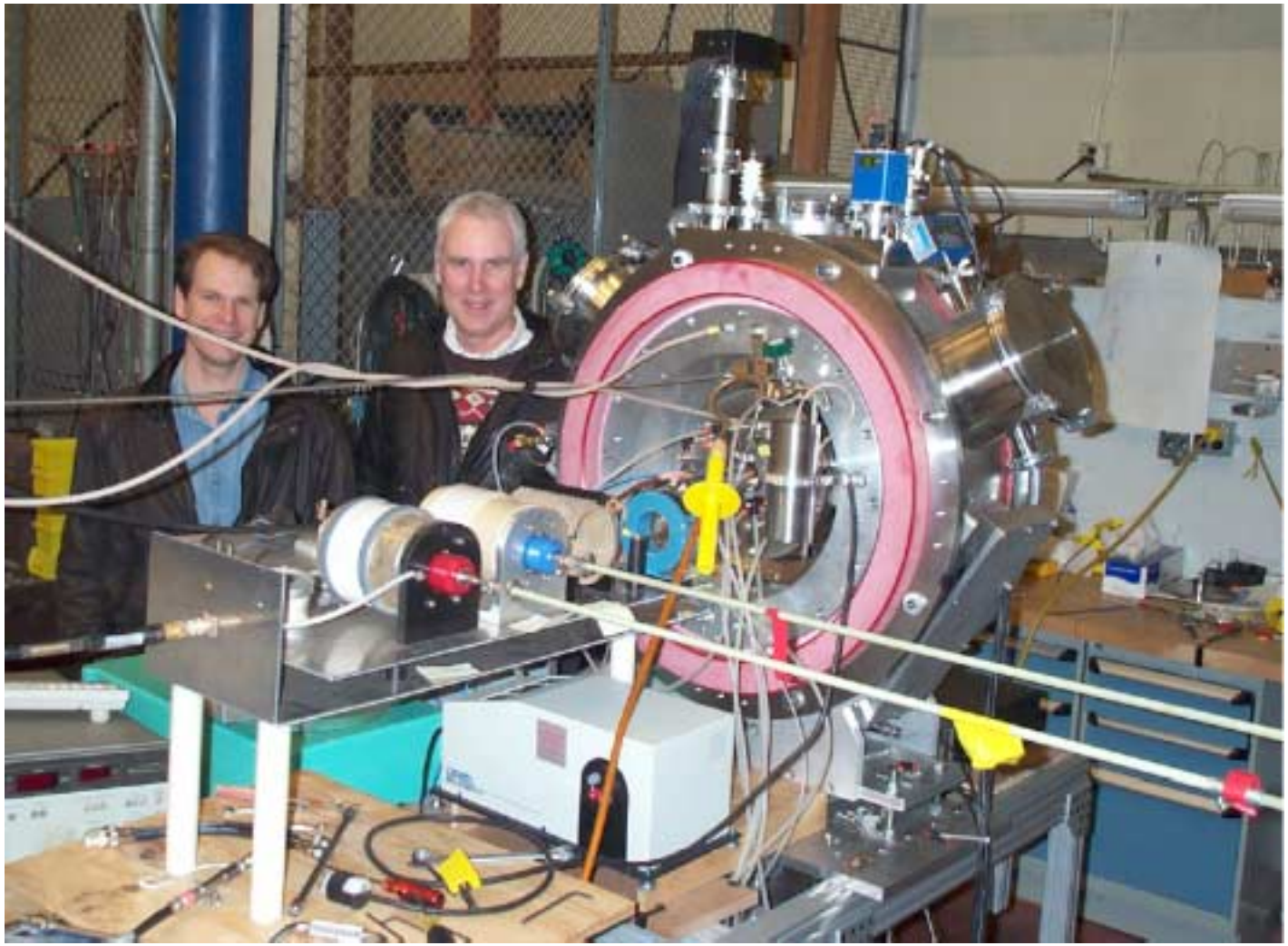
Match 40-mA beam into DTL

FES Integrated Testing Facility (Test Stand #1)



FES Integrated Testing Facility (Test Stand #1)

Ion-Source Test Stand #2



RFQ Module #1 Connected to LEBT on 4/19/01